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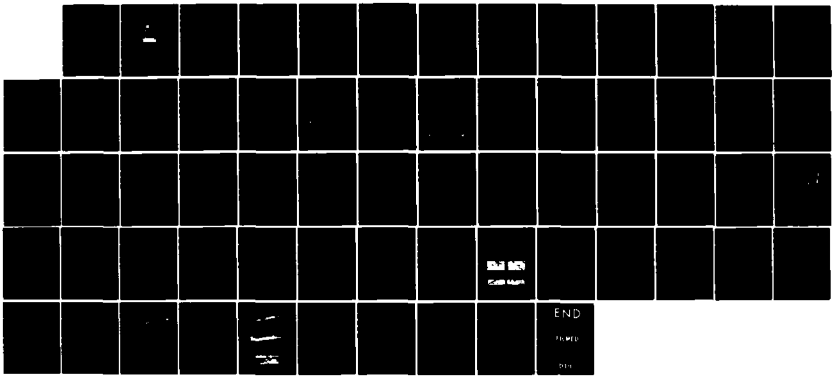

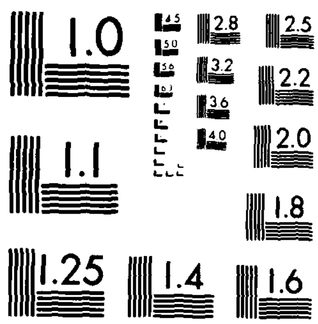

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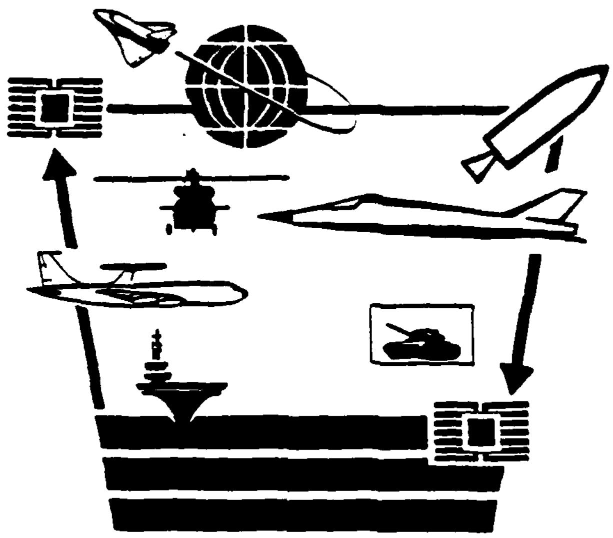
AD-A152 053

1982 TECHNICAL MEETING
AVIONICS SECTION
AIR ARMAMENT DIVISION

December 1, 2 and 3

US Air Force
Tactical Fighter Weapons Center
Nellis Air Force Base, Nevada



Program
AVIONICS TECHNOLOGY
AND
SYSTEMS DEVELOPMENTS

American Defense Preparedness Association
and the
American Institute for
Aeronautics and Astronautics

DECLASSIFIED EXTENDED ABSTRACTS

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PAVE PILLAR: AVIONICS ARCHITECTURE FOR THE 90's

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INTRODUCTION

This paper is written to apprise the advanced system architecture community of the rationale and planned activities under the PAVE PILLAR Program. This Program will be of fundamental interest in that: (a) the use of existing standards for projected architecture applications in the 1990's will be demonstrated; (b) the need for new potential standards will be assessed, with necessary developments accomplished and demonstrated in the framework of a backward compatible advanced architecture; (c) validation of the advanced architecture and its associated hardware/software elements will be accomplished through the demonstration of several representative avionic system applications; and (d) through a sequence of both ground and flight tests, the resulting architecture will be matured, along with associated potential standards, in order to establish a framework for avionics into the next century.

BACKGROUND - A PERSPECTIVE ON AVIONICS

In formulating a strategy for advanced avionics architecture development and maturation, it is first necessary to establish a perspective as to how avionics are currently used, their current limitations and what can be improved.

Today's avionics are placed on aircraft as a means to aid the aircrew in mission accomplishment. With a few exceptions, these electronic devices are separately developed and functionally integrated autonomously. (NOTE: Current architectures have mostly been used to replace wires - this physical integration has not yet substantially affected a change in functional integration). Dedicated outputs of separate subsystems are processed by the crew through the controls and displays subsystem. It is the crew's cognitive and psychomotor capabilities which are employed to perform information assimilation and to affect an action to a control element. In that our aircrews are already workload saturated, it is obvious that we cannot continue to merely add boxes or subsystems in a single thread manner. Later discussions will argue that an advanced architecture will be needed to permit functional automation for many missions in the future.

Secondly, today's avionics are difficult and expensive to maintain. Recent data show that approximately 25% of the removed avionics line replaceable units are judged to be fault-free at the intermediate shop for typical fighters. One quarter of our avionic maintenance personnel's time and one quarter of our spares are not being effectively utilized. Reasons for this situation run the gamut from simple to complex. For example, cables and connectors account for a great deal of the intermittent and "cannot duplicate" problem. (Although data is not routinely collected to substantiate the degree of the problem, interviews with maintenance personnel and a limited survey of reports indicates from 20% to 50% of maintenance actions originate from faulty cables and connectors). Further, maintenance difficulties have been compounded by failure prone BITE and inadequate failure monitoring and recording. In short, improvements need to be made in our ability to isolate avionic faults at the flight line. Again, inadequate diagnostic capability

is in part due to autonomous subsystem development. Later discussion will argue that an advanced architecture will be an essential element in improving availability.

What then is the root cause of current avionics problems? Obviously, the physical way which avionics is integrated in piecemeal fashion explains why automation and availability is lacking - this current architecture is however only symptomatic of the problem.

One school of thought blames much of our avionics-derived problems on advanced technology - viz. we are using complex systems which fail often and cannot be properly maintained. The argument is that we would be better off by using simple, inexpensive avionics but build more aircraft. Not only do the authors feel that such a position does not satisfactorily respond to survivability needs downstream; such a view does not correspond to factual data. For example, R. Little et al provide an excellent comparison of F-4 and F-15 capabilities, availabilities and technologies (Ref 1). Their conclusion, supported by data, is that technology has been falsely accused in limiting availability and support, as well as contributing to complexity.

The authors believe that many shortfalls in current avionics are due to three major factors:

(1) Lack of Technology

(a) Operating System/Architecture

Exploitation of available information on the aircraft, including automated process control between classical subsystems, is needed to not only reduce workload but to provide a means for integrated diagnostics. Such an approach requires a highly interactive operating system executive supported by wide band data distribution, high speed processing and extensive mass memory. Such technology was not available or adequately understood for inclusion in recent aircraft.

(b) Improved Subsystem Reliability

Increasing the inherent reliability of only a few high failure rate avionics will be extremely beneficial. Reduction in the number of cables and connectors through extensive multiplexing, deletion of mechanical elements (e.g., radar antenna drive train, mechanical gyros), deletion of components requiring high voltages (e.g., traveling wave tubes and CRTs) are keys to basic reliability improvements. The Air Force currently has several programs underway which will improve the reliability of radar, CNI, navigation and EW subsystems.

(2) Cultural Limitations

As avionics capabilities have grown over the years, organizations (both within and outside Government) have evolved which specialize in the development of functionally-oriented subsystems. For example, flight control, engine control, navigation, communications, electronic warfare, radar, stores management (etc., etc.) are considered "separate" entities and are for the most part developed and integrated separately (two notable exceptions are navigation/weapon delivery integration and terrain following radar/flight control integration). The authors believe that such "localized" thinking has, in the past, created a mind set which has slowed down possible progress in the automation arena. It is worthwhile noting

however that substantial improvements in automation of coordinated subsystem functions is dependent on the architectural technology.

(3) Avionics Maturation

Another school of thought contends that avionics reliability and testability will be improved if a more lengthy and iterative "fly and fix" approach were followed before commitment to production. As applied to advanced architectures, such an argument appears to be extremely sensible because of the fundamental role played by the architecture in influencing the entire avionics system over the life of the aircraft. "Guessing wrong" or inadequate testing may result in an extensive and expensive integration phase, may lead to frequent and expensive retrofits, may inhibit the isolation of faults, further compounding sparing difficulties, etc., etc.

In summary, current day avionics problems are not fundamentally due to technology; rather, had the technology existed and matured, many current-day problems would not exist.

FUTURE TRENDS IN AVIONICS: THE NEED FOR AN ADVANCED ARCHITECTURE

Projected threat density increases and threat mobility will result in a high flux environment where decisions must be made quickly and accurately conveyed to affect the appropriate action. Access to information and its subsequent exploration will be a key element of many successful operations.

External to the aircraft, communications, radio navigation aids, IFF and JTIDS information will play an important role in providing this information. The opportunities offered by this new "radio" capability will not be fully realized until several fundamental issues are resolved:

(1) Automated data handling/presentation of the information (particularly for threats);

(2) Affordability (plus weight and volume constraints for tactical aircraft) of the plethora of radio functions available;

3) Availability of the information in light of equipment failures and jamming environments.

The high flux environment expected will also require similar automated processes to be invoked on information internal to the aircraft. One recent study into future automation requirements concluded that trajectory and attitude control, engine control, weapon delivery and navigation were likely candidate functions (Ref 2). Both Air Force in-house and contractual studies show that information from across classical subsystem boundaries must be collected, blended or coordinated through automated process control and then distributed to appropriate displays or effectors, again back across classical boundaries. For example, automated trajectory control will require integration and coordination of navigation parameters (where am I?), JTIDS, stored threat files and electronic warfare receivers (where are the threats relative to me - which ones are new - which ones can cause harm?), stored terrain data for both terrain following/terrain avoidance as well as threat masking, propulsion/flight control and targeting and fuel data (how far is the target - what time am I supposed to be there - how much fuel do I have?). The coordination of this data will be necessary to determine new ingress/egress paths brought on by new threats or target redirect commands.

Human control over these coordinated processes and assimilation or monitoring of the resulting actions will also require new automation concepts in crew station design as well as substantial refinement and intuitive presentation of information. Use of voice control to change display modes, extensive use of color graphics to display distilled, overlayed imagery/stored data are examples of approaches which must be seriously pursued.

An advanced architectural approach will be needed to accomplish the integration, dissemination and presentation of information. Most obvious is the need for high speed data and video buses. For example, future aircraft are expected to employ large amounts of mass memory for terrain and cultural data as well as threat information. Correlation of this type of data, along with distributing large quantities of data for automated process control will lead to data bus requirements in excess of several MIL-STD-1553B buses (preliminary study indicates the need for a 20-50 Mbits per sec bus). Further, full compliance with MIL-STD-1760 in providing bi-directional video information between stores strongly suggests the need to explore video busing strategies to obviate the need for a large number of point-to-point cables.

An advanced architecture is needed to provide availability improvements. For example, extensive use of wide band buses can reduce the number of cables/connectors by up to approximately 90% (thereby reducing a major reliability problem). Extensive use of VLSI/VHSIC circuitry and distributed computing will also inherently increase availability, again through cable/connector reduction. Further, an integrated diagnostics capability which would permit the in-flight monitoring of BITE, correlation of data from similar information sources and recording of environmental data would reduce cannot-duplicate (CND) and Re-Test OK (RTOK) problems. Such a capability will also be required to achieve fault tolerant operation for both physical and functional redundancy. Thus, achieving improvements in availability as well as automation will be dependent on high speed busing to affect the needed connectivity.

The required topology and system control of the advanced architecture will be derived from consideration of several key factors. These factors include growth capability (i.e., to support both pre-planned and unplanned product improvements), degree of fault tolerance and failure containment, processing/bus efficiency, etc. Consideration must also be given to prime contractor/vendor responsibilities, to ensure appropriate consideration of the functional partitioning and interfaces between advanced subsystems and the system. Further, continued use of MIL-STD-1553B buses for overall system control and to permit future use of compatible hardware must be included in the topology.

Extrapolation of present trends indicates that many future subsystems will likely be configured as a bus oriented structure - hence, hierarchical busing interaction will be required. As with MIL-STD-1553B, the architecture should support high speed busing both at the global as well as at the subsystem level. Ultimately, high speed busing is expected to be used between standard modules within a subsystem to replace failure-prone connectors. Finally, a video bus structure is needed to operate under the control of MIL-STD-1553B. The latter bus will be needed to accommodate the bi-directional video distribution between stores, per MIL-STD-1760. It is envisioned that a frequency allocated approach similar to cable television will be used to distribute the large amount of video information between sensors, displays and "smart weapons." Development of a <u>standard</u> high speed data bus and a video bus will be needed to support this architecture.

Although the above topology will support virtually any projected system application or downstream retrofit, the relative simplicity of the associated executive operating system will be the key to utilizing the topology. The advanced operating system will be required to dynamically interact and control system and system/subsystem processes in near real-time. The operating system must accommodate fault tolerant processes at the global network level (e.g., failed bus) as well as directly interact with application software executing automated fault tolerant/safety of flight critical processes between subsystems. The degree to which the operating system can be exhaustively tested before airborne system use will determine ultimate acceptance. Consideration must also be given to standardization of application to executive software interfaces as well as subsystem/system standard interfaces in order to mature the operating system.

PAVE PILLAR STRATEGY - ARCHITECTURE MATURATION THROUGH DEMONSTRATIONS

Two key issues must be settled before deployment of the advanced architecture; (a) which new standards require development, and (b) determination of the scope/complexity of the resulting software intensive approach which accompanies the architecture. Simply stated, confidence needs to be established in the design before commitment. We collectively need to determine what we should do as well as what we should not do.

In recognition of this challenge, the PAVE PILLAR Program has been established. The strategy is one of maturing the system integration architecture through sequential validation demonstrations. The approach provides a low cost, rapid means of testing new integration concepts and high technology architectural elements and to develop design, performance and cost guidelines at the advanced development level. In so doing, the Program will greatly assist the Air Force in avoiding mistakes in attempting to implement approaches found to be too complex or inadequate to support availability needs, as well as assist in the earlier introduction technology shown to be effective. A large, non-proprietary data base describing designs, algorithms and software will be made available to industry. In providing the data base, it has been concluded that two levels of testing are desirable. The first level would take the form of a laboratory-based "avionics wind tunnel" - a means to quickly configure, demonstrate and test a given system configuration or potential standard at low cost. After determining high payoff approaches in the laboratory, the second level of testing would occur through flight testing on a generic test bed aircraft to gain further confidence in the results. Maturation of system integration technology requires coordination and inputs from the community in order to improve technology transition. In order to affect this participation, the PAVE PILLAR Program is coordinating its activities with AFSC Laboratories, ASD, AFLC, and the Using Commands. A wide range of contractual activities, as explained in a more complete paper on PAVE PILLAR (Ref. 3) will involve a large spectrum of industry participants.

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INTEGRATED COMMUNICATION, NAVIGATION AND IDENTIFICATION AVIONICS
ONE TECHNOLOGY STEP TOWARD INTEGRATED AVIONICS

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ABSTRACT: Communication, navigation and identification share portions of the electromagnetic spectrum to provide C^3 for aircaft, but projected electronic warfare environments will deny any effective wartime use of all conventional CNI which serves so well in peacetime. The need for protection against EW is urgent. Cost projections for the avionics components of separate solutions for voice, data, navigation and identification developed independently in separate engineering organizations traditionally responsible, show a tenfold increase for a full CNI suite for tactical aircraft. The result may be that full capability required may not be available because we cannot afford it. One alternative solution being addressed in service laboratories is an approach in which the whole CNI avionic suite is considered as a single design problem. Extensive exploratory development work in all three services has demonstrated feasibility of integrated concepts, and identified technologies and design approaches which could lead to an operational capability in the next eight to ten years. The potential benefits are high, especially savings in total cost and in demands for space in the avionics bay. There are pitfalls. The integrated approach which encourages pooling of resources from different disciplines instead of competing for limited development and acquisition funds, also brings with it the need for management effort in integrating the efforts of diverse technical groups. Organizations accustomed to selling traditional voice radios, TACANs or IFF transponders, see a threat to their market being taken over by a few system integration houses.

The paper describes the ICNIA program now in advanced development. It discusses the program, the system concepts, the supporting technology developments, the progress to date and the anticipated results. The program will also be set in the perspective of a recent DoD study by the Anti-Jam Architecture Working Group (AJAWG), showing how modifications to full scale development of individual systems can ease the transition to innovative approaches which today may appear revolutionary.

KEY WORDS: Integration, Avionics, C^3, Logistics, Graceful Degradation, Modular

ICNIA GOALS: To develop an operational mission effective airborne integrated CNI system.

ICNIA OBJECTIVES: ICNIA is an Advanced Development Program within service laboratories (AFWAL Avionics Lab, US Army AVRADA, US Naval Air Development Center) to demonstrate and validate the concept of integrating similar avionic subsystem functions in a single design concept. Its objectives are:

-To exploit analytic modeling and simulation capabilities to assess the effectiveness of the integration concept with respect to performance, cost, application of standardization, demands on logistics, retrofit, etc.

-To develop hardware and software terminals as examples of integrated architecture concepts developed in exploratory (6.2) programs.

-To develop an evaluation facility to bench test, flight test and evaluate advanced development hardware.

I. ICNIA PROGRAM BACKGROUND

EMPHASIS ON AVIONICS INTEGRATION. The CNI function in aircraft is implemented by a collection of boxes each performing a sub-function of CNI at some stage of the mission in one of a number systems most of which were developed some twenty to thirty years ago. None of the current systems is protected against EW. The development of new independent C, N and I systems within the C^3 environment requires an additional set of boxes, each five to ten times more costly than a box without AJ protection. For a prolonged period, each of the older subfunctions must be retained in the suite. This fact, coupled with installation costs which are projected in some cases to exceed the black box cost, results in our being unable to afford to implement anti-jam universally, even though the need is great.

INTEGRATION before the fact, or the approach which treats the total CNI avionics as a single subsystem, is one alternative to integration of an independent collection of boxes into the aircraft, after design development. In this approach, performance measures of the traditional kind (J/S, system throughout for data, etc have been demonstrated in prior development programs. The integrated system development can then concentrate on other measures of performance such as availability, supportability, easy integration into a variety of airframes. The application of new technology in timely fashion, pre-planned product improvement,technology transparency -- these become attributes of an integrated design possible in developing this alternative.

THE SCOPE OF INTEGRATION must be broad enough to be non-trivial (a two band radio is not challenging), constrained enough to be feasible. The total CNI function (including the inertial sensors) is a logical grouping and complex enough to be challenging. The risk is such that it cannot be attacked immediately as a full scale development; the concept must be demonstrated and validated in a laboratory program. It must also look ahead to those CNI systems not now in the inventory, but likely to be operational by the time an integrated CNI avionic terminal is fielded. Table I lists the current independent systems whose functions will be performed by ICNIA, with performance at least equivalent to the current or developing hardware. All these systems may or may not be operational in 1990, but constitute demonstration vehicles to test the programmability and flexibility of INCIA.

TABLE I, CNI FUNCTIONS FOR ICNIA

PJH	HF, VHF, UHF VOICE
JTIDS CLASS 2	VOR, ILS
SEEK TALK	MK XII TRANSPONDER, INTERROGATOR
HAVE QUICK	MK XV
SINCGARS	
GPS	

OPPORTUNITIES IN INTEGRATION. Without the neccessity for driving the traditional performance measures to the limit, since these have already been (or soon will be) demonstrated, the program can address many areas not normally considered in the advanced development stage. There are two areas of opportunity, technical and management. Technical considerations are: integration design which addresses the entire logistic support area (design for testability, repairability, support, support facilities, personnel skills etc.); the incorporation from the start of new concepts of fault tolerance and planned redundancy; a total concept of system costs; and compatibility with airframe (volume, environmental control, packaging and mounting). Both the integration of function and the "other" considerations imply a collection of skills and resources not normally found in one organization in a Laboratory. This requires that one look for opportunities related to management: full exploitation of current DOD research; active cooperation with skill centers in other organizations; the search for ways to fit this integration program into an overall avionic and C³ architecture; and the structuring of industry's relationship and understanding of the need for integration to provide the appropriate competitive environment in full scale development and acquisition.

II. PROGRAMMATIC CONSIDERATIONS

MANAGEMENT. The program office is in the Radio Systems Group of the Information Transmission Branch, System Avionics Division, Avionics Laboratory. It is one project under the PAVE PILLAR Program Element, the Advanced System Integration Demonstration. A significant aspect of the approach in ICNIA is: whatever R&D efforts, in any organization, have sufficient commonality, or a mutual interest in a technical area, exploit it to serve ICNIA purposes. "Do not reinvent the wheel." Several MOAs have been negotiated and joint efforts established with other organizations in recognition of the need to enlist skills needed or to exploit current similar efforts within DoD. These include:

In Logistics: with AF Acquisition Logistics Division to support the early incorporation of as many logistics considerations as possible, as early as possible in the development stages; with AF Human Resources Lab, Logisitic Research Division to apply their research of new concepts of support to the ICNIA development

In Technology: with RADC/EEA (Hanscom) to validate GaAs SAW technology, key to one of the architectures; with Naval Air Development Center, in validation of the applicabity of VHSIC technology to advanced digital signal processing (VHSIC Comm Signal Processor Brassboard); within PAVE PILLAR, in the development and application of a VHSIC 1750 ISA embedded data processor, the

application of fault tolerant structures and methodology, and in the potential application of control/display hardware proposed within the PAVE PILLAR program.

In ICNIA Development and Application: with the US Army AVRADA, as co-developers of ICNIA

One of the important programmatic considerations is driven by the recognition of the long development span with the result that fielded systems do not exploit the most recent and effective technology. The program management includes the need to incorporate methods of adapting as new technology matures; the DoD VHSIC program is a specific example. This program was not projected at the start of the ICNIA concept development, but is now incorporated as an "insertion" technology. The ICNIA program includes the requirement that contractors incorporate road mapping and transition plans in their attack on the design.

III. TECHNICAL CONSIDERATIONS

TECHNOLOGY. Concept development began in 1978, with a requirement to look ahead to 1985 for technology expectations, generate architectural concepts, validate the probable state-of-the-art of the most promising technologies during the ADM development, and modify the designs to accomodate reasonable risk technology. As these iterations of forecast-design-validate-revise have proceeded through the system definition phase, both technology and management considerations have focussed on the concept of continuing the forecasting to an assumed Engineering Development phase in 1987-88. Design tradeoffs have been directed at EDM as a goal, modified by the necessity to fabricate and test demonstration hardware in 1984 through 1986. The choice of implementing technology in ADM is thus governed by the mature technology projected to be available in 1988, coupled with the technology insertion plans to accomodate the actual developments as they arise in the future and contingency plans to accomodate late arrival of projected technology. The technologies which are important to the current planning are:

CCD and SAW delay lines with programming electronics built monolithically onto the delay line substrate (GaAs). These will provide the circuitry to implement highly programmable convolution or correlation algorithms for filtering (bandpass and interference suppression) and spectrum despreading of wide band signals

RFLSI will provide the means of shrinking the amplification and down-conversion circuitry which continue to be required at the receiver front end, by incorporating as many discrete circuits as possible into individual chips

VHSIC development was started after the ICNIA concept, but it appears that the thrust behind it is sufficient to ensure mature products by the time of ICNIA engineering development. It becomes therefore a significant technology consideration in ICNIA. It is probable that developmental products will be suitable for even the ADM phase of ICNIA, and validation of this assumption is proceeding in cooperation with the Navy

IV. SCHEDULE CONSIDERATIONS

Several factors have influenced the establishment of the ICNIA schedule. First is the need to be consistent with Laboratory procedures and procurement schedules, that is, to avoid schedules which require extraordinary management attention to meet. Second, somewhat in conflict with the first, is the need to avoid technological obsolescence of the product. Third is the balance required between offering a useful alternative to the new wave of anti-jam terminals being developed and proceeding faster than the system definition of the developing systems. This last is of particular concern with respect to the Combat Identification System, for which waveform, frequency, network protocol are yet to be defined, but for which operational dates around 1988 are projected. Should the architecture proposed by the Anti-Jam Architecture Working Group be implemented within existing programs, the potential of new waveforms will continue to be of concern and will be monitored closely.

V. COST CONSIDERATIONS

COST AS A PERFORMANCE MEASURE OF THE DEMONSTRATION PROGRAM. It has been noted above that J/S performance is not the driver of ICNIA. A successful integration program must demonstrate the technical feasibility of common modularity in hardware and software, the time sharing possibilities, the fault tolerant reconfigurability and the improved performance in availability. To be of value beyond the device and circuit technology base, it must provide convincing evidence of its value as a system design approach in order to justify proceeding through further development. This justification must include two areas: impact on the aircraft (space, weight, prime power, environmental control system demands, aerodynamic penalty of antennas); and the cost of acquiring, deploying and upgrading an integrated system as compared with a suite made up of independently developed black boxes. The decision to proceed to full scale development will require confidence that the benefits to be obtained justify the investment in further development. A clear payoff in overall costs plus the less easily dollar quantified factors of space saving and mission availability will provide such justification. The assessment of cost factors involved, plus estimates of the "market" within DoD for an ICNIA, consitute an important part of the ICNIA development. Preliminary analyses of paper designs suggest that goals of saving one third to one half for total costs, and 40 to 60 percent for volume, (compared with a collection of independent systems) are attainable in production hardware.

VI. OTHER CONSIDERATIONS

TRANSITION. The ICNIA program is not in the business of developing new waveforms, frequency bands, formats or network protocol. Its driving purpose is the solution of avionics problems in the areas of affordability, availability and aircraft compatibility; it is predicated on the basis of a need which will ensure implementation of ICNIA in full scale development if the promises are fulfilled. At least part of the return is in the ability to expedite the process through full scale development; this can only be fulfilled by close liaison with the

product development division which will execute the Engineering Development Program. No Product Division has been designated (August 1982) as having EDP responsibility, but liaison is being maintained through a Management Advisory Group, consisting of the AFSC product divisions, representation from logistics (AFALD) and the US Army development agency. While this will provide satisfactory guidance in the initial stages of the program, it will be necessary to determine an appropriate development "customer" if the DoD is to fully exploit attempts to reduce the total development cycle.

ANTI-JAM ARCHITECTURE WORKING GROUP. In October 1981, the AJAWG was chartered by OSD to review anti-jam programs in development. Findings and recommendations have been presented and (August 1982) the concepts developed by the AJAWG are being reviewed by an AFSC working group, whose task is to recommend in detail changes required in Air Force development programs. The concept recommended by the AJAWG is to exploit the significant redesign now under way in the SEEK TALK (antijam voice) program to determine how a degree of commonality can be achieved between waveforms and implementing hardware of the SEEK TALK, JTIDS and MK XV designs. The technology exists today to build signal processing modules which can be programmed for multiple applications. In the normal mode of engineering program offices, designs would be optimized for the function addressed by that program office without regard for multiplicity of function outside of the program office charter; but in this case, each of the program offices is being required to review what synergism can be found in a cooperative approach. Since the operational date of SEEK TALK is earlier than that of the MK XV, this could be viewed as requiring SEEK TALK to leave a "legacy" for the MK XV, and further requiring that the MK XV program exploit this legacy. A major impact could be that hardware developed when MK XV goes operational is "backward compatible" (in hardware, signal waveform etc) with previous developments. Any success in achieving modular commonality will be of benefit to the ICNIA program, since it will demonstrate a minimum integration of C and I function which will clearly facilitate acceptance of the ICNIA principles. Introduction of ICNIA into operational hardware then becomes the final step in an evolutionary path of successive stages of integration rather than a revolutionary leap.

ARMY NEED FOR ICNIA. Compared with the limited space available for Avionics systems on a modern Air Force fighter aircraft, Army aircraft might be expected to enjoy the luxury of ample space and weight requirements for the avionics necessary to perform Army aircraft fighting and support missions. Although this may have been to some extent true in the past, sophisticated armament systems, navigational aids, communciation, and identification systems coupled with the high technology ECM threat have greatly increased the necessary avionics aboard Army aircraft. Fighting techniques are continuously being updated to improve effectiveness in a highly sophisticated, quick changing electronic battlefield. For example, Army aircraft are now forced to fly at Nap-of-the-Earth (NOE) altitudes to avoid detection and destruction by electronics directed weapon systems. NOE (low altitude) flying places severe demands on communication and navigation systems increasing their complexity and therefore their size, weight, and cost. Yet these systems become more crucial to the mission success and pilot safety.

The pilot and navigator's full attention is required to guide the aircraft above and around obstacles. Minimal time can be afforded for operation of CNI systems. The next generation Scout, Utility,Attack Army rotary aircraft, the LHX, targeted for the 1990's timeframe has a specific need for an integrated CNI architecture (Ref 1). A new role for the LHX includes air-to-air defense in addition to improved performance on conventional helicopter missions. The LHX avionics architecture must be implemented in highly integrated standard hardware and modular, redundant software which are easily reconfigured to accomodate changing mission needs and/or component failure. As communication, navigation and identification systems become more sophisticated to satisfy future aircraft mission scenarios thoughful integration to conserve precious space, weight, power and cost resources is the only alternative that will make possible the fielding of a mission responsive aircraft.

1. LHX Avionics Architecture Technical Report, Feb 1981, Semcor, Contract #DAAK80-79-C-0258

AMRAAM Operational Utility Evaluation

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The Air Force Test and Evaluation Center (AFTEC) conducted the Advanced Medium-Range Air-to-Air Missile (AMRAAM) Operational Utility Evaluation (OUE) from March 1981 to January 1982. The evaluation was conducted concurrently with the competitive AMRAAM validation phase tests. Essentially, the OUE was to determine the impact of AMRAAM on the outcome of combat scenarios in comparison with current weapon systems. Current systems for the F-15 were the AIM-7M, AIM-9M and gun, while the F-16 carried the AIM-9M and gun. The AMRAAM Decision Coordinating Paper, 13 January 1979, directed the OUE to address the following areas:

a. The utility and performance of AMRAAM with and without reliable identification friend or foe (IFF).

b. The utility of multiple target capability in a realistic air combat environment.

c. The impact of various types of parent aircraft avionics on the effectiveness of AMRAAM.

d. The workload requirements imposed on the pilot while employing AMRAAM.

The OUE analyzed applicable data from the Air Combat Evaluation (ACEVAL) Joint Test as an initial step and then conducted a man-in-the-loop simulation.

The man-in-the-loop simulation test was accomplished at the McDonnell Douglas Corporation simulator Facility, St Louis, Missouri. The facility was modified to provide simulation of up to 12 manned combatant aircraft and to incorporate simulation of a complete armament suite for each aircraft. The combat environment was as realistic as possible and included clear air conditions, weather conditions consisting of a solid cloud deck, electronic countermeasures (ECM), and communications jamming (COMJAM). The ECM simulation provided multiple ground-based jammers and up to eight self-screening jammers. The combatants engaged in combat air patrol (CAP) and fighter sweep scenarios. The full factorial test included all combinations of the following parameters:

a. Weapon system (F-15 and F-16, with AMRAAM or with current weapon systems).

b. Avionics system (single-target-track (STT) or multi-target-track (MTT) radar). (In this report, MTT and TWS radar are used interchangeably.)

c. IFF (with reliable IFF (BVR rules of engagement (ROE)) or without reliable IFF (within visual range (WVR) ROE).

d. Scenarios (CAP or sweep missions).

e. Environment (benign (clear air mass) or adverse (ECM, COMJAM, and weather)).

Tactical Air Command (TAC) provided a cross section of experienced fighter pilots and ground-controlled intercept (GCI) controllers for this test. Eight F-15 pilots, eight F-16 pilots, and six GCI controllers made up the Blue Force teams. Forty additional pilots, current primarily in the F-4, F-106, or F-5, flew the Red Force representative threat fighters and fighter-bombers.

Data from each valid trial were recorded in real time from the main simulator computer. Pilot debrief data were merged with mission data after the trials. All data were then reduced with an automated data-reduction system to form data banks for analysis.

To ensure that results are used within the context of the test, the following qualifications apply:

a. All countermeasures (ECM and COMJAM) were against Blue Forces.

b. No ground-based threats or installation defenses were included.

c. Not all aircraft systems were modeled completely, e.g., the radar homing and warning (RHAW) system provided only an estimate of threat direction with quadrant lights.

d. If kill criteria were satisfied, an aircraft was immediately removed from the trial (real-time kill removal). Otherwise, the attacked aircraft was free to continue the engagement. Criteria based on lesser degrees of battle damage were not modeled.

e. The AMRAAM digital model was a generic model based on joint system operational requirements (JSOR) and joint system program office (JSPO) specifications.

f. Evaluations were based on the relative differences in results. Individual results should not be used in absolute terms.

The test was divided into two phases. Phase I was the initial checkout and training phase during which development of the simulator configuration and test

procedures were finalized. Phase II constituted the formal test and included 1,252 valid trials equating to over 13,000 fighter sorties. Over half of these trials were divided among F-15 CAP, F-16 CAP, F-15 sweep, and F-16 sweep missions. The remaining missions were flown as sensitivity excursions to determine the effects of various scenario and environmental changes.

The results were defined by certain measures of performance (MOPs). The conslusions were drawn by analyzing all the MOPs and observing how the test variables interacted. There were over 100 MOPs defined for the test, but the majority of the analysis centered on the overall engagement outcomes which were loss rates and the percentage of Red bombers successfully reaching the target.

The numerical results for each MOP were displayed in a matrix defined by weapon system, type of avionics, rules of engagement, and environment and force ratio. Any interactions observed involved these variables.

The specific answers to the OSD areas of interest are classified and will be presented in the OUE briefing rather than the abstract.

Information was obtained in many other areas such as missile launch ranges, missile effectiveness, tactics, avionics effects, IFF effects, Red weapons employment, etc. The OUE data can thus be used to answer many other questions both technical and tactical.

TACTICAL FLIGHT MANAGEMENT

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Automatic systems providing full or partial control of fighter aircraft have recently been developed for weapon delivery and real-time flight management applications. Integrated flight/fire control technology has been demonstrated inflight for air-to-air and air-to-ground gunnery and unguided bombing in the Integrated Flight and Fire Control (IFFC) program using a modified F-15. This technical thrust was extended by the Integrated Flight/Weapon Control (IFWC) program to include the delivery of guided weapons and dispenser munitions. On a parallel front, fundamental real-time flight management technology was developed by a series of Air Force-sponsored studies under the aegis of Integrated Flight Trajectory Control (IFTC). The aim of these studies was to increase the capability for real-time flight management through automatic coupling of the navigation system to the flight control and propulsion control systems to achieve time-critical mission objectives. This technology is sometimes referred to as automatic 4-D (time and space) navigation.

The subject Tactical Flight Management (TFM) program builds on this technology foundation to develop a TFM system which enhances total mission effectiveness through coordinated application of integrated control technologies (Figure 1). The program is split into three phases, each about one year long. Phase I concentrated on system definition and was recently completed. The results

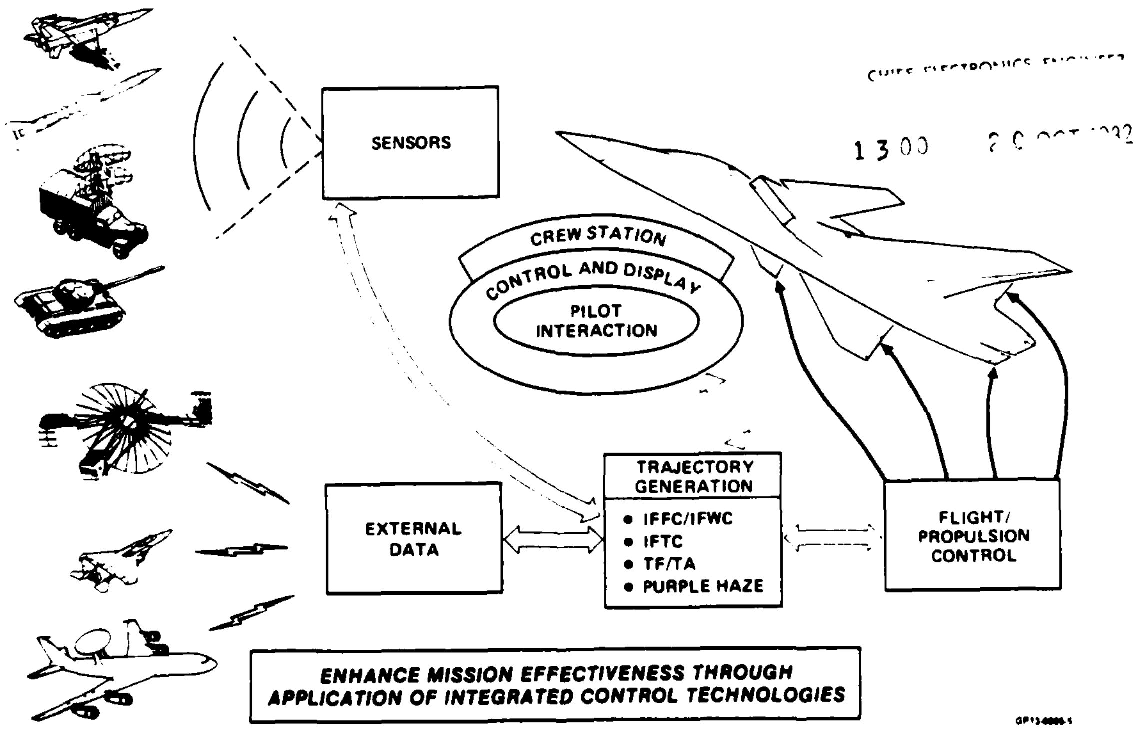

Fig. 1 Tactical Flight Management

are summarized herein. Phase II has been underway for only a short time. It will carry out system development through the preliminary design stage and will incorporate two advanced technologies which make use of stored digital terrain data, terrain following/terrain avoidance and threat penetration/display. Phase III will consist of a pilot-in-the-loop evaluation of the TFM system using the McDonnell Aircraft Manned Air Combat Simulator.

A top-down approach was used to define the TFM system. Tactical air combat scenarios and aircraft performance anticipated for the 1990's were throughly reviewed. Based on this review, capabilities were identified which hold promise for increased overall weapon system effectiveness. Existing and projected 1990 technologies were then selected for incorporation into the TFM system to provide required capabilities.

MISSIONS

The functions and capabilities of the TFM system have been selected to improve the capabilities of existing tactical aircraft, to enhance the effectiveness and improve the survivability of aircraft which will have to operate in an increasingly sophisticated threat environment, and to complement the performance of advanced aircraft and weapons now in development. TFM requirements were established based on a variety of operational combat mission scenarios. Each mission was analyzed to identify areas that could be improved by the application of integrated control technology.

The missions used were based on operational studies conducted by two advanced crew station development programs being conducted in parallel with TFM. Air-to-air missions considered included combat air patrol, sweep, escort, and air intercept missions. Air-to-surface missions reviewed to develop requirements include close air support, battlefield interdiction, and offensive counter-air (deep interdiction).

REQUIREMENTS

Why do we need a TFM system? The need for an advanced navigation and flight control system is the result of highly lethal air defense systems, including both surface-to-air missiles and radar controlled anti-aircraft guns. The battlefield of the 1980's and 1990's will be exceedingly well defended. In addition, the rapid pace of modern warfare does not wait for good weather. The next generation fighter must retain its effectiveness at night and in inclement weather. The basic requirement of the integrated TFM system is to penetrate enemy defenses and deliver ordnance accurately under fire and in low visibility without taking unacceptable losses.

The system requirements were established by dividing the mission into segments and considering the requirements for each segment. Figure 2 illustrates those capabilities considered necessary enroute; while Figure 3 illustrates capabilities for weapon delivery.

SYSTEM DEFINITION

Providing these capabilities requires a highly sophisticated, multifunction, multiloop control system. General mission goals are translated into a flight plan which, in turn, results in slowly changing, low bandwidth flight path commands. However, the system must also provide individual, high bandwidth surface deflections and engine commands throughout the flight envelope. Thus, the basic function of the TFM system is to translate general mission goals into specific control actions in a safe, reliable manner.

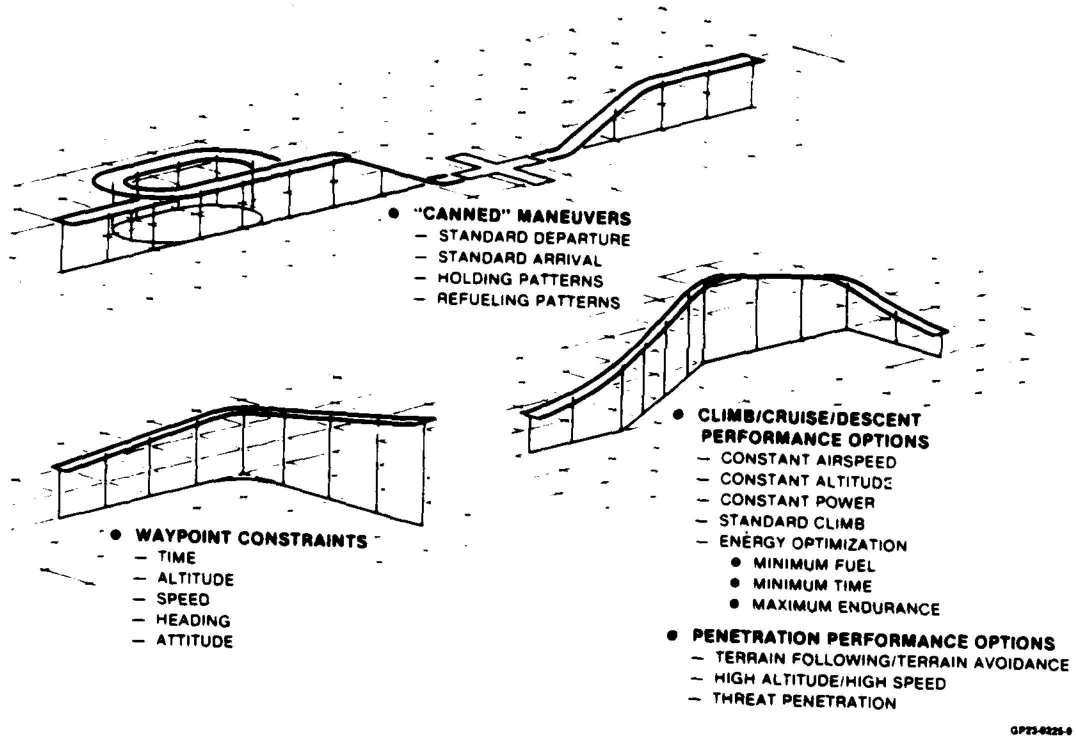

Fig. 2 Enroute Capabilities

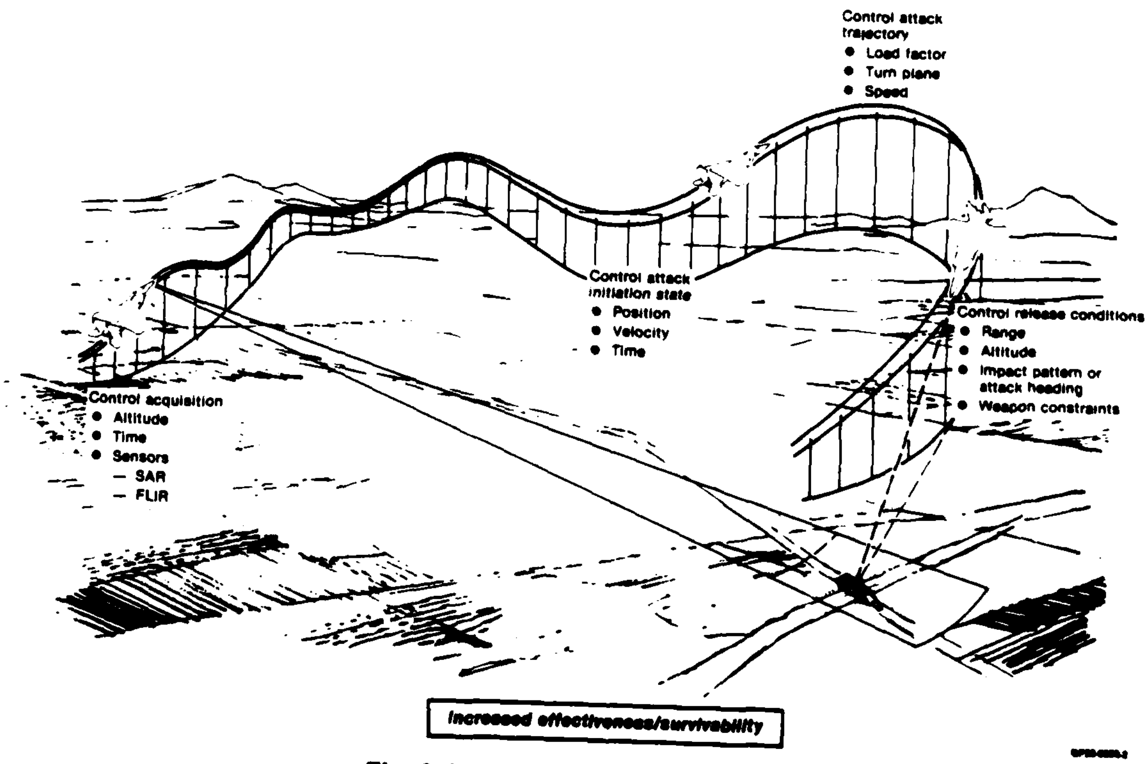

Fig. 3 Weapon Delivery Capabilities

In our approach to formulating a TFM control structure the system is divided into a Trajectory Generator and a Tracking Algorithm (see Figure 4). The Trajectory Generator blends the flight plan with pilot control actions and estimates of aircraft, target, threat, and terrain states to derive both a reference trajectory and trajectory commands that specify the trajectory's local characteristics. The Tracking Algorithm operates on the trajectory commands, pilot inputs, and estimates of aircraft state to generate the surface deflections and engine commands that result in airframe forces and moments.

A range of pilot control from manual to fully automatic is provided. The pilot can run the gamut from top-level system manager to precision controller. This flexibility is available throughout the mission and greatly enhances the system's ability to gracefully degrade under subsystem failures.

Redundancy is a required feature for a system as complex as TFM. The system must maintain both safety of flight and mission capability. The highest redundancy level is provided for subsytems which directly control aerodynamic surfaces and engines. Flight and propulsion control is highly redundant with as many as three or four parallel systems being compared to validate proper operation. This degree of redundancy is required to insure controllability and maintain safe flight.

NEXT STEPS

During the next year, TFM system development will be continued through the preliminary design stage. This activity will include detailed digital simulation, identification of subsystem accuracy and computational requirements, and recommendation of system hardware and software architectures. After preliminary design, we will be in a better position to quantify the potential operational payoffs of the TFM system and to assess the practicality of mechanizing it.

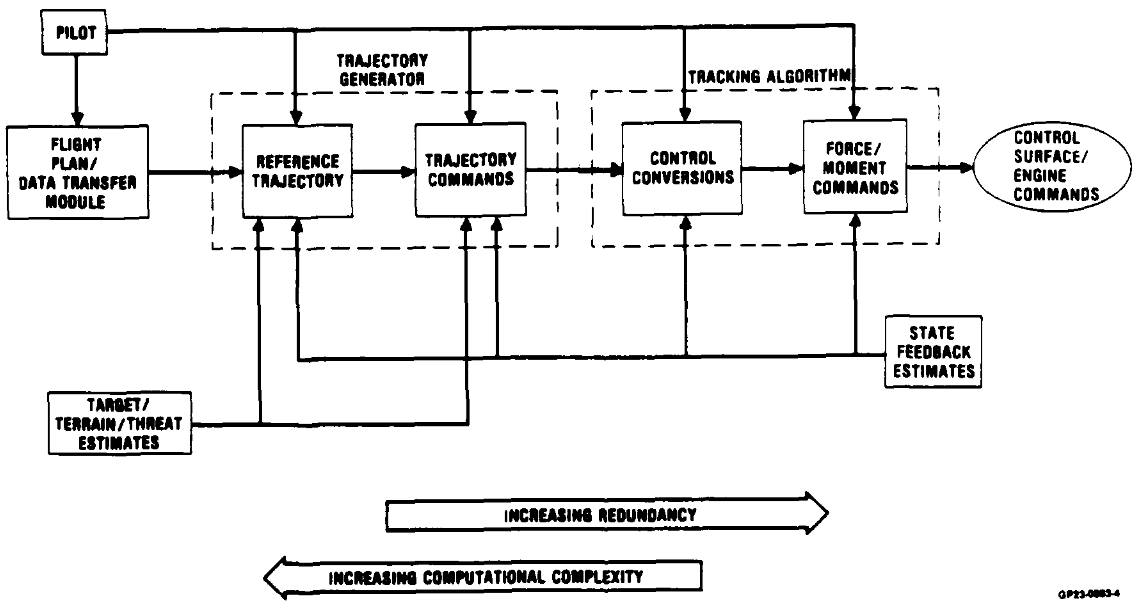

Fig. 4 TFM Control Structure

SESSION II
ALTERNATE I

24

PAPER TITLE: FIGHTER ATTACK EMITTER TARGETING SYSTEM (FAETS)

CLASSIFICATION: Will Be SECRET

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ABSTRACT:

Background. The ever increasing use of the electromagnetic spectrum to conduct tactical operations imposes more severe requirements on strike aircraft than ever before. At the same time, the successful execution of air support missions requires that these hostile EW environments be pentrated with acceptable attrition rates. The need to increase aircraft survivability is obviously urgent. NOSC, under ERASE sponsorship, has undertaken studies to specify future signal environments expected in tactical operations. Conclusions from these studies are frightening due to the emitter densities. Furthermore, signals associated with advanced enemy radars already in the field or scheduled for deployment within the next decade will have challenging transmission formats, forcing difficult new intercept requirements on all receivers.

However, the threats have been detected and identified to the strike aircraft, the problem focuses on the use of such data. Obviously, if the emitter continues to radiate, an ARM could be launched to destroy the source. Experience has shown, however, that radar tactics are subtle. Radars can simply be shut down when certain features are observed. More sophisticated radar control will make wide use of netting (coordinated transmission) and C^3 links for radar control. The impact of these tactics is to reduce mission effectiveness.

The ERASE Program recognized the radar shut down problem and the threat this poses to strike aircraft. Consequently, the ERASE-sponsored MSLS Program was initiated specifically to address this problem. The objective of MSLS was to acquire and precision locate a radiating emitter passively and hand-off location data to an active radar for tracking after shutdown. However, since the conception of MSLS, significant advances have been made in small, precision antenna arrays and higher preformance receiver systems. More significantly, precision broadband passive DF systems are now possible using fixed-mounted antennas, thus facilitating a passive DF cueing system which can significantly enhance aircraft weapon delivery through complementary operation with other aircraft systems and without interfering with their normal operating modes. The system that does this is FAETS.

FAETS Concept Summary. FAETS (Fighter Attack Emitter Targeting System) is the next generation precision DF cueing system designed for Navy high performance aircraft such as the F/A-18. This system provides forward port and starboard coverage and receives all present and expected future threats.

FAETS is a direct outgrowth of technology stemming from ERASE-sponsored programs such as MSLS and Advanced Receiver Development as well as from technology applied to the HARM missile. FAETS combines the collective technology basis of:

- Broadband, size-reduced spiral/helix antennas and advanced fixed-mounted amplitude/interferometer DF techniques.

- High Probability of intercept hybridized IFM/Microscan receiver systems.

- High-Speed processing based on advanced HARM avionics computers.

- Compact, cost-effective, stripline receiver subsystem packaging.

One example of the practical reality of FAETS is demonstrated by the HARM CLC . This machine handles system control functions, processes system analog and digital data, and interfaces directly with standard aircraft data buses. A high-speed, advanced capability version of the CLC will be used in FAESS. Work to support the modified CLC is already underway.

Another example of the practical reality of FAETS is the ERASE-sponsored Advanced Receiver Technology programs which have yielded microscan receiver technology and systems configuration specifically directed to the FAESS problem. Such receiver technology has been successfully demonstrated and is capable of handling all known present and future threat signals. At the same time, these advanced technology receivers can meet sensitivity, dynamic range, and frequency accuracy and resolution required for FAETS.

This paper is therefore a timely submission of a system concept that is being realized now to do a difficult and necessary job. This paper describes the three year proof of concept program written around the use of a full scale development aircraft such as the F/A-18, to conduct tests on the Navy ECHO Test Range at China Lake, California. The feasibility demonstration requires only the removal of this aircraft gun to accommodate the brassboard hardware and instrumentation. Full integration with the aircraft FLIR, DBS radar and rolling map display will be provided.

<u>FAETS Concept Paper Summary</u>. The presentation will a discussion of the FAETS Operational Scenario, followed by the FAETS Description and Operation. FAETS Specifications will be given, as well as the difinition of the FAETS Operating Modes.

FAETS Subsystem Hardware Design for the antenna, receiver, and processing subsystems, will be discussed. A mechanical configuration for a FAETS Demonstration Flight Test System and a configuration for a longer-term production system will be given.

The final part of the paper will present a Program Plan for the Flight Test Demonstration System and program.

SESSION II
ALTERNATE 2.
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& Maj Ronald L. Thacker

ASSESSING THE COST EFFECTIVENESS OF AVIONICS THROUGH THEATER LEVEL MISSION AREA ANALYSES

The purpose* of this proposed paper and briefing will be to give a brief description of a theater level model developed by U.S. Technologies for ASD/XR and ASD/AX to assess the cost effectiveness of avionics and other weapon systems/subsystems, and to describe example results to show how the model can be used to compare the cost effectiveness of both similar and different types of avionics (e.g. LANTIRN, an air-to-surface mission avionics system, and Infrared search and track, an air-to-air mission avionics system) by assessing their impact and cost at the theater level. A brief description of the model is provided below.

The UST Mission Area Analysis Model is data file fed which allows mission analyses to be based on data from existing studies or more detailed models/simulations. In addition to the models ability to use data from more detailed simulations, it can also be used to perform first order assessments and scope the areas where more detailed simulation/model runs are needed thus reducing the computer time needed for large scale models/simulations. The ability of the UST model to use data from a variety of sources and its speed and ease of operation make it clearly suitable for tasks that require a quick turn around. Outputs of the model include both cost and effectiveness at the theater level, with full mission interaction, so that systems can be easily prioritized based on their cost effectiveness, regardless of the mission area in which they are used.

The UST methodology is based on the use of closed-form probabilistic models for all modeling purposes, together with a modular data flow structure which enables all computer programs and subprograms to operate from a single, integrated data base. The broad use of segmented data files and analyses subprograms is maintained to enable UST to implement the entire analysis process on a single desk top general purpose digital computer. The capacity of UST general purpose digital computers used for this purpose is 64K RAM and 500K disk storage, with both data files and subprograms stored on a single eight-inch floppy disk. The typical run time for an integrated ten-day mission area analysis of a combined US/NATO vs. Warsaw Pact conflict is about five minutes on one of the UST desk top computers.

The UST model is designed to provide the US Air Force with a comprehensive capability to analyze force effectiveness and cost effectiveness of combined Air Force assets, at the theater level. The model can be used to integrate the combined influence of present and potential future aircraft, avionics, armament, logistics and

basing options on the overall effectiveness and cost of the Air Force at the theater level. The simultaneous examination of all these factors, across a spectrum of Air Force missions, provides a unique tool for use by the Air Force planner. Cost and corresponding capabilities can now be examined, for the first time by a single analytic tool, when making investment tradeoffs between new aircraft, modifications and improvements to existing aircraft, increased commonality and supportability between aircraft, expanded basing, new or improved avionics and new or improved armament. Furthermore, explicit quantitative inter- dependence between various Air Force systems is provided, as a basis for quickly-and authoritatively -assessing the impact of individual programmatic actions on the utility of other Air Force systems, in combination.

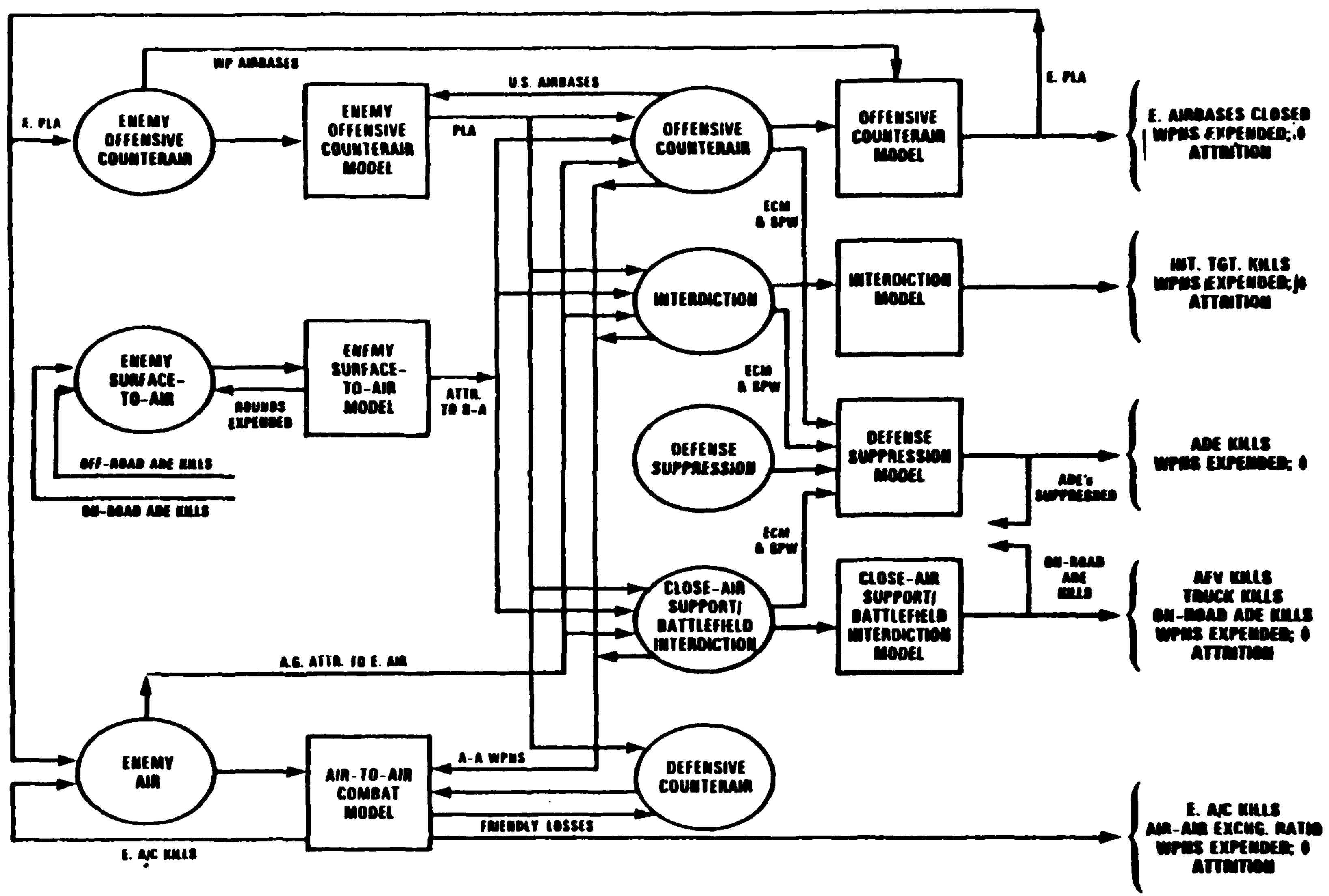
The credibility of the methodology has been established by UST under previous Air Force support efforts to AD/XR and AF/RDQ, under Air Force contract F08635-80-C-0172. The VANGUARD analyses for AD/XR provided an interactive assessment of opposing counter air capabilities, over time: fighters and bombers killed; airbase prelaunch availablility, as a result of both friendly and enemy airfield attacks; shelters destroyed; sheltered and unsheltered aircraft killed and other factors. Alternative armaments considered included: AIM-9 series, AIM-7 series and AMRAAM; MK-82R, MK-84R, DURANDAL, BAP-100, JP-233, HAMMER, MRASM, NATO SSM, CBU-58, CEM, GBU-15/CADM and others. The FY 81 Combined Armament and Avionics Investment Strategy, in support of planning needs for AF/RDQA, expanded the theater level modeling to include five mission areas: defensive counter air; offensive counter air; defense suppression; close air support and battlefield interdiction; and interdiction. It evaluated combined theater level performance, and cost, as a function of a large number of aircraft, avionics and armament options, including: IRST; EO Cueing; RF Cueing; JTIDS; SEEK TALK; PAVE MOVER; LANTIRN; PAVE TACK; ASARS; Advanced ECM; LRAAM; AMRAAM; SPW; MRASM; HAMMER; NATO SSM; WASP; HVM; T-16; F-16XL; STRIKE EAGLE; LOCUST; and LRCA.

The mission area structure used by UST is shown in the attached figure, and includes a relatively high degree of inter- dependence between performance in one mission area and its resultant impact on capabilities in other mission areas. The introduction of both friendly and enemy forces in the computerized model is on a common basis, sharing a common data file. This insures that similar forces, when introduced on either side of the modeled conflict, will produce equivalent results, as is the case in "real life." The NATO capability in battlefield interdiction, for example, is coupled directly to the expected prelaunch availability of battlefield interdiction support airbases. These, in turn, are dependent on both friendly and enemy capabilities in offensive counter air, as established by their corresponding data file values.

The data files for each system contain some fifty parameters that can be varied based on the outputs of level 3 modeling, e.g. number of systems, speed, weapon loadout, probability of detection, probability of valid launch, weapon velocity, probability of kill, etc. The data files also contain the cost of each weapon system and weapon. The basic structure of these mission models does not change and the outcome is based soley on the number,type, and performance paramaters of enemy and friendly systems entered into the data files. The data files can also be used to vary the theater of operation , e.g. from Europe to the Middle East. Measures of merit include, Cost, FLOT movement, Degree of mission goal achieved (number of targets killed), and survivabiliity (number and percentage of friendly aircraft killed and source of kill broken out by enemy threat system).

The data flow structure has been developed, and demonstrated, to provide an "upward compatible" integration of all Air Force system and subsystem capabilities that are considered. Thus, for example, direct "traceability" is readily established between the particular capabilities of an Air Force subsystem-such as the capabilities of of the subsystems in LANTIRN -and its corresponding impact on the overall capabilities of the Tactical Air Force. The impact of improved or degraded capabilities of systems like LANTIRN can readily be traced, manually or automatically, not only to the impact on the particular mission area in which the system is being employed, but also to the "collateral" impact that it is expected to have on other mission areas which may peripherally be effected. Thus, for example, the target identification capability of LANTIRN, in a battlefield interdiction mission, would indirectly impact the survivability of aircraft in other mission areas through an improved lethal suppression of mobile enemy air defense systems (such as SA-8's and ZSU-23/4's). Similarly, an improvement in avionics "standardization" would result in an increased sortie generation rate, with attendant increase in overall force effectiveness.

INTERACTIVE TACTICAL AIR WARFARE MODEL



ELLIPTICAL BLOCKS AND LINKS NOT LABELED CONTAIN INPUT DATA AND ASSUMPTIONS ON FORCE STRUCTURE RESOURCES, SYSTEM EFFECTIVENESS, AND CONCEPTS OF OPERATION

Inverse Synthetic Aperture Radar - Applications In Naval Aircraft

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J. M. Smith, Texas Instruments, Inc. Dallas, TX

The Soviet surface navy has grown into a modern force operating throughout the world. It is fully integrated with the air and sub-surface elements and is supported by sophisticated surveillance, C^3 and over-the-horizon systems. It is equipped with medium and long range surface-to-air and surface-to-surface missiles. Response to this threat requires antisurface warfare (ASUW) forces with over-the-horizon (OTH) systems for target acquisition, analysis and command and control. To satisfy these requirements the OTH system must have the following capabilities:

- Detection of potential targets at ranges allowing effective OTH weapon employment.
- Discrimination and classification of targets outside defensive envelopes.
- Location of the target with sufficient accuracy for employment of OTH weapons.
- Damage assessment.
- Communication of threat data to cooperative platforms.

At present our aircraft have only limited capability for the ASUW mission. Airborne radars can detect large targets at adequate ranges and a limited number of such radars can detect small and medium targets at such ranges, even in moderate to high sea states. Few of these radars possess the resolution and capability to discriminate individual targets in a densely populated area.

Classification of detected targets by present systems also fails to satisfy the OTH requirements. Visual observation and acoustic, electro-optical (EO) and electronic support measures (ESM) systems are used. Visual observation and electro-optical systems both require close approach to the target, well within the defensive envelope. Both are subject to environmental conditions such as darkness, fog and heavy precipitation. Acoustic classification and localization requires planting a sonobuoy field in a suspected target area prior to target arrival. Also, an acoustic contact may not provide an area of probability small enough to meet targeting requirements. ESM systems can intercept and classify targets at long ranges. However, no range information is available and angular resolution is usually such that correlation with the radar detection is difficult, and imposition of EMCON conditions by the target denies our forces the use of the ESM equipment for classification.

Recognition of the shortcomings of available classification methods has led to sustained interest in using the radar return for classification of the detected target. One method which has been the subject of extensive study and development has been the range-only classification scheme. In this scheme the range-versus-signal amplitude

profile of a target is analyzed either manually or automatically to determine the class of the target. The Royal Air Force is presently utilizing the manual system along with computer aids for the operator. Two shortcomings of this system are the skill and experience required in the operator and the limited aspect angles over which useful information is available. Another shortcoming is the ease with which passive countermeaures can render the technique ineffective.

The automatic range-only classification approach is being developed at present by the Naval Weapons Center, China Lake, California. Promising results are being obtained. This approach will be the subject of later discussion.

A second method for radar classification which has been the subject of long-term intensive investigation is the use of the Synthetic Aperture Radar (SAR) map or image for surface target classification. SAR radars use high range resolution and a large synthetic antenna aperture to obtain a map with high resolution in both the range and the azimuth or cross-range dimensions. This technique is excellent for stationary targets and is successfully used for high resolution mapping over land and for detection and classification of land targets. However, use on ocean surface targets has not been satisfactory. Motion of the target such as pitch and roll generates undesired doppler components, resulting in scatterer displacement and the resultant smearing of the image. In moderate to high sea states this effect, also referred to as "de-focusing", results in an unrecognizable image.

Numerous studies have been conducted by both government and private organizations in attempts to compensate the SAR image for the target's own motion, with little if any success, although some recent studies appear to have developed promising approaches. The Naval Research Laboratory for a number of years conducted one of the most comprehensive programs on image compensation. In the course of these studies Dr. David Kerr conceived a method for obtaining an image of an ocean surface target using the target's motion itself. Dr. Kerr developed this concept and demonstrated it in the laboratory using data obtained in the course of the image compensation studies. As a result, the Naval Research Laboratory and Texas Instruments, Incorporated under NAVAIR sponsorship, have developed a system utilizing this principle. A high range resolution radar, the AN/APS-116, was modified to provide the imaging, commonly referred to as Inverse Synthetic Aperture Radar (ISAR) imaging. The developmental system was installed in a P-3A aircraft and extensively tested over a variety of operational areas including the Mediterranean Sea. The system has also participated in a number of fleet exercises. The results obtained have been excellent and demonstrate that the technique provides long range target classification with a high accuracy rate.

As implied by the similarity in names there is a close relationship between ISAR target imagery and conventional SAR mapping techniques. Both concepts have a common theoretical base and generate high resolution two-dimensional visual presentations by processing coherent radar signals. The displayed information is of a photographic nature in the sense that radiation reflected from an illuminated object is used to

produce a view corresponding to a projection from three dimensional space onto a plane. Although similar in this respect, major differences exist between the radar images produced using ISAR techniques and those obtained by optical methods. In particular the shadowing effects are dissimilar because of the different orientation between the plane of projection and the line of sight between the sensor and the target.

The orthogonal axes used for the display of both SAR and ISAR images represent directions parallel to the line of sight, range, and perpendicular to the line of sight, cross range. High resolution in the range dimension is attained by the use of narrow transmitted pulse widths or pulse compression techniques. Radial velocity, and its effect on the returned signal phase, is used for resolution in the cross-range direction. The source of the motion responsible for the cross-range resolution differentiates between the ISAR and SAR concepts. SAR mapping is totally dependent on radar platform motion, whereas target motion is the predominant contributor to radial velocities and cross-range resolution for ISAR image generation.

ISAR images are essentially maps indicating the location and reflectivity of the component scattering elements comprising a target. The positions of these elements are indicated on a display using Cartesian coordinates proportional to range and cross range. Reflectivity, or radar cross section, is indicated by varying the intensity of the display in accordance with the amplitude of the returned radar signals. Range locations are determined by measurement of the round trip transit time of the returned signals. Cross-range measurement is dependent on target motion, with the radial velocity of the target being proportional to its cross-range location.

Generating the cross-range location requires selecting a reference point on the target and measuring target rotational motion relative to that point. A fundamental prerequisite for imaging is that any relative motion between the radar and the reference point must be compensated so that only the effects of target motion remain. The motion compensation is achieved through highly precise range tracking and doppler tracking circuit functions to stabilize the reference point in both dimensions.

From the viewpoint of the operator, detection of a surface target and generating an image of that target is a relatively simple process. The radar is operated in one of the non-coherent high resolution modes for target detection. When it is desired to classify a detected target, the trackball is used to position a target designator symbol (TDS) over the target. The target will then appear on the B-scan, which is an expanded presentation of the portion of the PPI display immediately around the target. Depending on the selected range scale, the B-Scan represents 22.5^{0} in azimuth and either 2 or 4 nmi in range extent. The B-Scan is situated in the upper right corner of the PPI display. With the target shown on the B-Scan, the trackball is used to more accurately center the TDS about the target. The antenna is "searchlighted" on the target and the image mode is selected. The radar then automatically locks on to a large scatterer on the target and image processing is initiated. A continuous or real time image is displayed. The operator may freeze up to four images for analysis and can expand either the

continuous image or one of the stored images to occupy the entire display. The on-board computer is used to provide interactive classification aids for the operator. A track-while-scan (TWS) feature in also incorporated. In addition to the maintenance of a surface plot and of a track file for command and control use, the TWS circuits provide aspect angle and heading information to the on-board computer and to the operator, to aid in target classification.

While classification is relatively simple and can be performed quickly, operating in densely populated ocean areas can overload the radar operator, particularly when he is also responsible for operation of other sensors. As mentioned earlier, the Naval Weapons center has developed an automatic range-only classifier that is very accurate in classifying targets as combatant or non-combatant. Use of this type of classifier for target presort is being evaluated, and provisions are being incorporated into the radar for providing the desired signal for that unit.

The AN/APS-116 Radar Set now in use in the S-3A aircraft is being modified to the AN/APS-137(V) configuration as part of the S-3 Weapon System Improvement Program (WSIP). Upon fleet introduction of the WSIP modified S-3A aircraft, then designated the S-3B, the fleet will for the first time have a sensor which will permit detection and classification of surface targets outside their defensive envelopes with the accuracies needed for OTH targeting. This ability to detect and classify targets outside their defensive envelopes is extremely important and alone justifies the modification program. But other important benefits accrue to the aircraft. The S-3A or S-3B aircraft is a multi-sensor aircraft using sophisticated sensors and scenarios to perform its mission. In most cases the radar imaging can be used to classify targets without interfering with the flight patterns necessary for other sensors such as acoustic sensors. Further, elimination of the need to fly close to detected targets for classification can result in a several-fold increase in area coverage and/or in overall mission effectiveness or alternately, a decrease in the assets required for a given mission. The modification program also provides the opportunity to improve performance, reliability and maintainability of the radar. Such improvements are an important part of the program.

Planning is also under way for installation of the AN/APS-137(V) Radar in the P-3C aircraft. The radar and its capability will be essentially the same as that of the S-3B aircraft although new developments may permit a drastic increase in the radar's target detection range in time for incorporation in the P-3C program. Such new capability would of course be available for back-fitting into the S-3B radar set. The ISAR imaging concept is also under consideration for other aircraft with ASUW missions. New or modified attack aircraft can be expected to incorporate this capability.

The incorporation of the ISAR capability in fleet aircraft with an ASUW mission will provide for the first time the ability to accurately detect, classify and target hostile surface targets at stand-off ranges, essentially independent of environmental conditions and hostile force actions.

LIASAR (LASER INERTIAL
AIDED SYNTHETIC APERTURE
RADAR)

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LIASAR (LASER INERTIAL AIDED SYNTHETIC APERTURE RADAR)

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The LIASAR Program, sponsored by Naval Air Systems Command, will provide an integrated avionics capability for weapon delivery with application to light attack/fighter aircraft. The program integrates a light-weight synthetic aperture radar with a Ring-Laser-Gyro-based inertial measurement unit to provide both high resolution radar ground mapping and precision navigation (including In-Air Alignment) at substantial savings in hardware. Status and test results will be presented.

1. INTRODUCTION

The program evolved on the premise that current light attack aircraft have deficiencies in all weather/night operations capability. Several of these aircraft (e.g., A-4, AV-8B, A-10, etc.) have no all weather sensors at all and others (e.g., A-7E) have sensors which represent 20-year-old technology. Conventional all weather/night operations systems are too expensive and are physically incompatible with light attack aircraft.

The LIASAR System is an integrated avionics solution to the problem. The objective is a feasibility demonstration of an integrated radar/navigation system with application to all weather/night operations weapon delivery for light attack aircraft. The constraints guiding the development include cost, reliability/maintainability, pilot workload (single seat aircraft assumed) and physical constraints (size, weight, power).

LIASAR integrates existing hardware technologies to achieve synergistic benefits. Specifically, LIASAR is composed of a light-weight Synthetic Aperture Radar (SAR), a programmable digital signal processor, a Mil-specified General Purpose Computer (GPC) and a strapdown Inertial Measurement Unit (IMU) which employs Ring Laser Gyros. Software integration of these subsystems and radar and navigation functions results in an avionics system suitable for the light attack mission.

Emerson developed the light-weight SAR and programmable signal processor with its IR&D funds. Naval Air Systems Command (NAVAIR) is sponsoring the multi-year program under Contract No. N00019-80-C-0613 and is providing the strapdown IMU. The IMU is part of the Advanced Tactical Inertial Guidance System (ATIGS X-0) developed by Honeywell under NAVAIR sponsorship at the Naval Weapons Center. It incorporates three, GG1300 Ring Laser Gyros and a triad of accelerometers. While ATIGS is itself a proven inertial navigation system, LIASAR interfaces directly

with the IMU sensors to perform radar-aided navigation using its own navigation software package. Synergistic benefits are derived by using navigation system outputs for SAR motion compensation and conversely, by using radar measurements to update the navigation system state through a Kalman Filter.

The integration of the radar with the navigator has also led to an In-Air Alignment mode in which radar measurements align the inertial navigation system after takeoff. This mode requires no operator interaction and imposes no constraints on the aircraft flight path. More importantly, it offers the operational advantage of minimizing the time required to become airborne.

The LIASAR program has included hardware and software integration of the system elements followed by test and evaluation at critical milestones to reduce overall risk. These test phases are:

1) Hardware-in-the-Loop, Bomb Navigation Software Validation Test/Evaluation,
2) Motion Compensation Test/Evaluation,
3) Rooftop Test/Evaluation,
4) Flight Test/Evaluation.

The first two milestones were achieved in FY'81 and reported upon at the December 1981 Technical meeting of the ADPA. The third milestone was achieved in FY'82 and is discussed herein.

2. SYSTEM DESCRIPTION

A Functional description is followed by descriptions of the hardware and software.

2A. FUNCTIONAL DESCRIPTION

The navigation system and radar control reside in a single general purpose computer. The strapdown IMU provides the high-iteration rate motion sensing required for inertial navigation and, by close placement to the radar antenna, provides the motion compensation needed by the SAR. In turn, the synthetic aperture radar is used to accurately measure radar observables to achieve a precision radar-updated navigation capability with application to weapon delivery.

SAR measurements of line-of-sight (LOS) velocity over land and LOS range to the sea surface update the navigation system. These SAR measurements utilize the monopulse characteristics of the antenna to achieve high accuracy. The velocity and range measurements are processed through a 16-state navigation Kalman Filter to damp the Schuler velocity and position errors. Another mode is the position update in which SAR measurements of LOS range, range rate, and azimuth and elevation angles to prestored checkpoints are used for updating.

Table 1 provides a summary of the system modes and performance. Figure 1 provides a qualitative measure of the navigation performance imporvements achievable using radar-aided navigation. The velocity update mode provides a 10-to-1 improvement over free inertial navigation in over land applications. The range-to-sea surface mode (unique to LIASAR) provides a 6-to-1 improvement over conventional navigation systems in over-water operation. The position update using high resolution SAR maps provides 100 foot rms position accuracy.

2B. HARDWARE DESCRIPTION

A pictorial block diagram of the LIASAR flight test hardware is shown in Figure 2. The system operates at X-band. A dual-axis monopulse flat plate slotted array provides a 4.8 degree azimuth and an 8 degree elevation beamwidth. The transmitter provides 8k watts of peak power at 2% duty cycle using a crystal controlled X-band excitation to a Litton, Ring Loop Traveling Wave Tube Amplifier (TWTA). Bi-phase modulation is used for pulse compression to achieve 40 foot range resolution. Low noise, GaAs FET RF amplifiers in the receiver monopulse channel minimize the system noise figure and enhance system performance. A frequency synthesizer is programmed by the GPC to track the clutter doppler reference frequency. Its output provides an appropriate reference for down-conversion of the IF signals to baseband for subsequent SAR processing. To retain both amplitude and phase information, both In-phase (I) and Quadrature (Q) components of the Sum and Difference channel signals are formed. Azimuth and elevation Difference signals time share the Difference channel by diode switching at the antenna. The four video channels (Sum I, Sum Q, Difference I, Difference Q) are amplified and filtered (overall bandwidth of the receiver is matched for 40 foot resolution) prior to A/D conversion in the synchronizer at a 12.5 MHz rate. The synchronizer stores the sampled data (640 range cells) in PRF buffers where it is accessible by the programmable signal processor (MSSP/DP). The processor performs all SAR and monopulse signal processing and display processing under the control of the GPC. A control and display console is provided for operator control of both radar and navigation modes. The display serves the roles of radar display for mapping, navigation advisory and checkpoint editing/monitor for the operator. Antenna servos and power amplifiers are in the power/electronics unit.

The IMU is housed in the ATIGS X-0. Motion sensing is accomplished by a triad of ring laser gyros (2^{-17} radians/pulse) and a triad of Sunstrand Q-Flex accelerometers (2^{-6} fps/pulse). The LIASAR interface with ATIGS is directly to the IMU.

The ROLM 1664 GPC was selected as the LIASAR data processor for interim tests. The GPC incorporates the integrated navigation/radar control software described below.

2C. SOFTWARE DESCRIPTION

The integrated navigation/radar control software resides in the GPC. All software modules were developed in a Higher Order Language (FORTRAN) for transportability. The software package incorporates a 16-state Kalman Filter which provides optimal processing of radar measurements for navigation updates. The barometric altimeter is included in the Kalman Filter as opposed to using a separate second order baro filter, for example. This has led to convergence of initial large pitch and roll errors in the In-Air Align mode as discussed below. The software is formulated so it could incorporate measurements from other sensors such as GPS, JTIDS, FLIR, etc., as updates if they were available. Major system error sources (e.g. antenna bias, gyro bias) are included as states to obtain improved estimates of the primary navigation parameters. Inertial coordinates are utilized for the navigation computing frame and for setup of the stabilized map/track coordinates during the map/measurement modes. The use of inertial coordinates reduces the computational load (over using a rotating coordinate frame) and simplifies radar control parameters. The use of a common coordinate system means fewer coordinate transformations are required and simplification of the Kalman Filter "measurement matrix" (relating the radar measurements to the navigation parameters being updated) is realized. The attitude (quaternion) propagation and navigation integrals are done at a 100-Hz iteration rate. This provides motion compensation signals (line-of-sight accelerations) at the high iteration rates required and provides navigation capability for highly maneuvering aircraft.

The programmable signal processor (MSSP) includes software for pulse compression (variable-length complementary codes), doppler processing (variable-length presum filtering and FFT's) and other processing associated with SAR and monopulse measurement modes.

3. IN-AIR ALIGNMENT

The In-Air Alignment problem is that of establishing the attitude of the inertial "platform" after takeoff. Typically, the alignment is done on the ground in a two-stage process. In the first stage, local level is established using accelerometer outputs to sense and correct level misalignments while a magnetic compass is used for a coarse heading. In the second stage, gyrocompassing, using gyro outputs indirectly, is used to fine tune the heading alignment. To improve the response time of operational aircraft it is required to minimize or eliminate the amount of time the aircraft must remain on the ground for the alignment process.

The LIASAR In-Air Alignment is performed as the aircraft is in route to its destination. SAR measurements of LOS velocity over land at a sequence of azimuth and elevation angles are used to determine aircraft velocity in all three inertial axes. These velocity measurements are the reference for comparison to the inertially-computed velocities. "Feedback" of the error signal through the Kalman Filter results in alignment in level and heading in much the same way as on the ground.

Level misalignments are corrected first and heading misalignment is subsequently corrected as the residual heading misalignment evolves into a pitch misalignment.

The In-Air Align mode starts by initializing (on the ground) the inertial attitude using an assumed local level (pitch = 0, roll = 0) and a magnetic compass (corrected for local and aircraft variation) for heading. Inertial navigation then begins as the aircraft leaves the runway. The LIASAR's Kalman Filter-coupled barometric altimeter reduces pitch and roll errors as the aircraft climbs to altitude. The radar is then engaged to make the velocity measurements. These short-dwell-time measurements (one every three seconds) at the inertially-stabilized beam directions impose no operational constraints on the aircraft. The only requirement is to keep the antenna pointing below the horizon. Some violation of this will not cause a severe penalty-only the alignment time will be affected. ("Reasonableness" tests in the Kalman Filter reject measurements made when these conditions are violated.) Since position errors are included as states in the Kalman Filter, accumulated position error during alignment is minimized. No position update is required at the end of the alignment.

Simulation results have shown that In-Air Alignment can be completed in about 15 to 20 minutes with a final heading error of about 1 milliradian and pitch and roll errors below a tenth of a milliradian. These are equivalent to typical final ground alignment accuracies. During this time, the accumulated position error is held to less than one-half a nautical mile. In addition, rooftop tests of radar-aided "In-Air Alignment" (discussed below) have indicated that the alignment times may be less than this.

4. ROOFTOP TEST AND EVALUATION

The third major milestone was the integration and test of all hardware and software in Emerson's Radar Tower to evaluate system performance prior to flight testing. This milestone was successfully completed in FY'82 and a Rooftop Preliminary Design Review was held with the Navy on 23 and 24 September 1982.

Rooftop tests consisted of three phases. In Phase 1, functional tests of system interfaces and control signals were completed. Input power, sensor inputs (IMU, radar, etc.), system control (radar set control, navigation control, etc.) and other signals paths were verified. In phase 2, open-loop tests measured signal levels end-to-end in selected modes. Radar transmitter power and efficiency at all three LIASAR transmit frequencies were measured. SAR signal processing in the MSSP was checked by injecting a test signal with a variable time delay (range delay) and doppler offset. Antenna characteristics were measured including calibration of the monopulse Sum and Difference channels.

The final phase was system closed loop testing. A water tower and two smokestacks were used as test targets. A major portion of these tests included verification of map (SAR) processing with all 3 resolutions (40 ft, 80 ft, and 160 ft) using real radar returns from the hard targets. Proper phase coding of the transmitted pulse as well as

processing of the return pulse (pulse compression, FFT processing, etc.) for a variety of conditions were verified. In addition, synchronizer parameters (sampling time, etc.) were modified to demonstrate 20 ft. resolution. Although the receiver bandwidth was designed to handle 40 ft. resolution (overall bandwidth is about 10 MHz), operation in the 20 ft. resolution mode was demonstrated with some expected smearing in the range dimension due to the mismatched receiver bandwidth.

Another major test included that of radar updated navigation using "all hardware-in-the-loop", i.e., real radar measurements and real IMU data. Testing of the position update mode using the LOS range and range rate measurements to two prestored checkpoints (the water tower and smoke-stacks) was completed. During the position update tests, velocity and position errors in the navigation system caused the target to move away from the center of the displayed "map". The operator then placed a cursor over the displaced target and, by hitting the acquisition button, caused the range and velocity measurements to update the navigation system through the Kalman Filter. Correction of velocity and position errors was successfully demonstrated.

In-Air Alignment was tested, to the extent possible in the rooftop, by using the LOS velocity measurement alone. In a typical test of this mode, a 2^{o} pitch and roll error and 3^{o} heading error were intentionally entered at the start. Then a 60-second ground alignment was performed. Free inertial navigation then began with about 0.2 mr pitch and roll error and 25 mr (1-1/2 degrees) heading error. Radar velocity measurements were then made after five minutes of "flight". Inertial velocity errors decreased with each measurement. A total of forty measurements was made over a 13-minute period. Final velocity errors were less than 0.5 FPS and final heading error was about 0.65 mr (less than the 1.0 mr spec). Further analysis of the data indicated that the same heading alignment would have been achieved sooner had the measurements occurred more rapidly, as they would automatically in the operational system. Position error at the end of alignment was less than 0.1 nautical miles. The entire fixture holding the radar and IMU was rotated in AZ, EL and Roll axes (to partially simulate aircraft motion) during some of the measurements.

5. SUMMARY

The LIASAR program has successfully completed all program milestones. The program plan called for flight test to begin in late FY'82 and continue into FY'83. The flight tests were to be conducted in a Navy T-39D at the Naval Weapons Center. However, no Navy funding has been allocated for the flight tests.

While Emerson and the Navy continue to work to identify flight test funds, improved system performance, including growth to 10 ft resolution and In-Air-Alignment over water are being investigated on company IR&D funds. The LIASAR system is currently still in the rooftop test facility where hardware improvements are being incorporated.

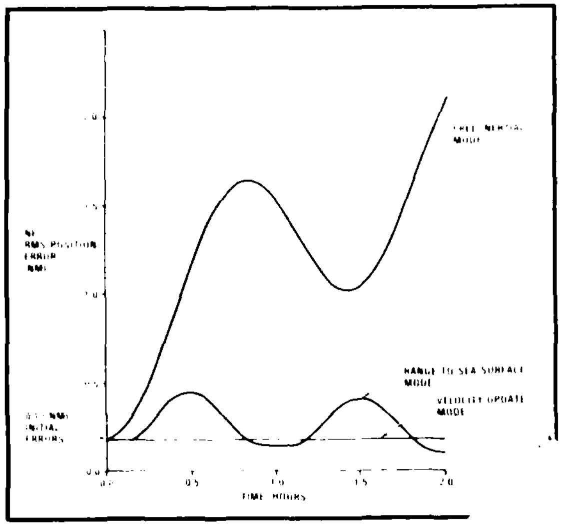

FIGURE 1 RADAR-AIDED NAVIGATION PERFORMANCE

TABLE 1. LIASAR PROGRAM GOALS

• NAVIGATION ACCURACY	
— VELOCITY UPDATED OVER LAND	0.3 NMI/HR
— RANGE-TO SURFACE OVER WATER	0.5 NMI/HR
— POSITION FIXED (15 MINUTE INTERVALS)	100 FT RMS
• IN-AIR ALIGNMENT	
— TIME TO ALIGN	15 MINUTES
— ACCURACY	1 MRAD AZ
	0.1 MRAD LOCAL LEVEL
— POSITION ERROR	≤ 0.5 NMI
• GROUND ALIGNMENT	
— TIME TO ALIGN	4 MINUTES
— ACCURACY	1 MRAD AZ
	0.1 MRAD LOCAL LEVEL

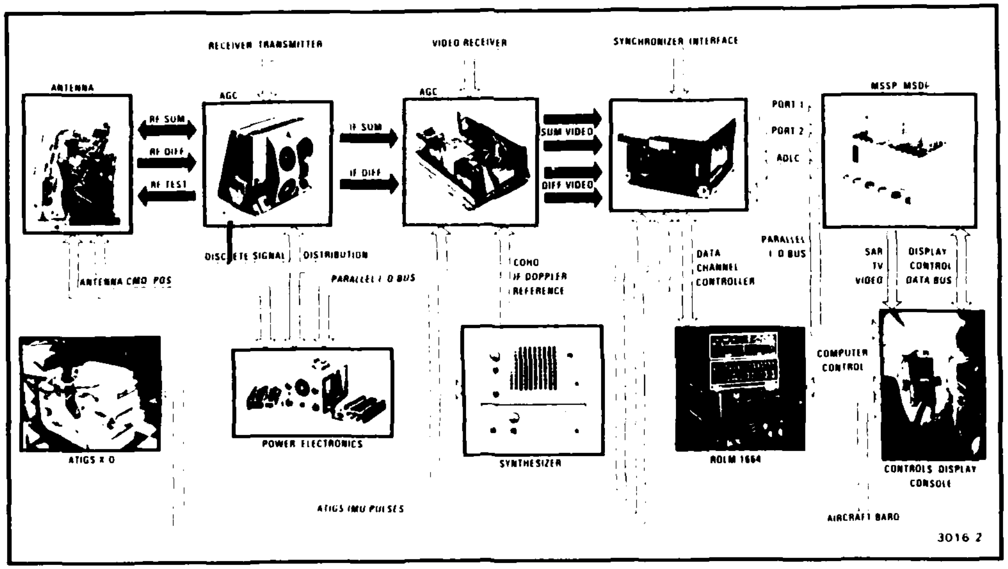

FIGURE 2 FLIGHT TEST HARDWARE BLOCK DIAGRAM

5347-1

PREPRINT

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ADVANCED WEAPON HANDOFF TECHNIQUES FROM AN AIRBORNE FLIR POD

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ABSTRACT

Feasibility of a Lock-On-After-Launch (LOAL) weapon system is discussed. The system concept is based on initial target acquisition at long standoff range by a tactical airborne FLIR, and handoff to a precision launch weapon with low cost imaging seeker. This is an intermediate concept/solution between the Lock-On-Before-Launch (LOBL) and the fully autonomous fire and forget weapon. System issues and benefits are presented. Without arguing the relative merits of weapon system concepts, the critical feasibility issue of implementation of reliable image correlation (scene matching) algorithms is emphasized. Unique handoff algorithm aspects for data filtering, segmentation, shape analysis, and image labeling are discussed. Results of both active and passive (emphasized) image scene matching experiments are presented. Finally, the preliminary design process for a self-correlation seeker is presented.

INTRODUCTION

The limiting missile function for precision air-ground weapon delivery is target acquisition that achieves high standoff or minimum exposure to the air defense threat yet provides a high probability of kill for the weapon concept.

The optimum solution to precision weapon delivery at low risk may be a fully autonomous imaging (passive or active) seeker which provides automatic target acquisition and terminal homing; much fruitful work continues in development of such system concepts. At the other end of the spectrum of imaging, smart seekers are LOBL systems. The availability of high performance navigation and targeting pods such as the Ford Aerospace Pave Tack (F-4 and F-111 applications) and F/A-18 FLIR pod systems, and emerging developments in pattern recognition and processing provide the impetus for the intermediate system concept of the LOAL seeker supported by FLIR imagery. The concept and system implications are discussed in this paper.

THE ELECTRO-OPTICAL POD SYSTEMS

Current electro-optical targeting pods produced by Ford Aerospace are direct outgrowths of the Pave Knife system which provided surgical strike capabilities in conjunction with laser guided bombs near the close of the Southeast Asia conflict. Both Pave Tack and the F/A-18 FLIR provide day/night infrared imagery with selectable narrow and wide fields of view for identification and search. Imagery in both systems is highly isolated from aircraft vibrations, and scenes can be ground stabilized to provide continuous area viewing or target tracking throughout high g-loading maneuvers. The current operating modes of the Pave Tack system are illustrated in Figure 1 as representative of the class of electro-optical pods used in the following sections. Key to the LOAL concept is the high performance capability of Pave Tack for long range target acquisition and precision weapon launch in the tactical environment.

THE OPERATION CONCEPT

A sequence of events envisioned for the self-correlation seeker is illustrated in Figure 2. The aircraft approaches the target area at low altitude. In the vicinity of the target area, the initial point (IP) is acquired

and tracked, and the aircraft inertial navigation system (INS) updated. The weapon INS is aligned to the aircraft INS. At long standoff range, the aircraft pops up to acquire the target area using the wide field-of-view optics. The operator steers the FLIR line-of-sight to the vicinity of the desired aimpoint. The narrow field of view is then selected, and the line of sight is fine aligned to the aimpoint which is then tracked. A frame of imagery is passed to the missile, and stored. The missile then is launched on an inertially guided path toward the target. During inertial flight the pod imagery is digitized and processed to provide a reference model for subsequent scene matching. At short range the seeker begins imaging the target area. Real time seeker imagery is matched to the reference model and the aim point selected. Computed offsets of the seeker imagery provide the basis for terminal homing maneuvers.

ADVOCACY OF THE CONCEPT

As mentioned earlier the lock-on-after-launch system described here occupies the middle ground between lock-on-before-launch and autonomous weapon systems. The primary advantages over current lock-on-before-launch systems are much longer standoff and greatly reduced exposure, reduced operator work load and accommodation of off-axis weapon delivery. Relative to fully autonomous systems, the pod assisted LOAL weapon advantages accrue to full operator control, with real time selection of the aim point, significant cues associated with relative contrast of objects in the scene and simplicity of electro-optical design. The field of view of the seeker must be only large enough to accommodate tactical navigation and launch errors (which are small) with no need for search mode gimbal set and attendant high costs. Design parameters including resolution, minimum resolvable temperature, and noise equivalent temperature need only be sufficient to provide image quality at very short range consistent with the FLIR long range image quality. Minimal image quality requirements translate to small aperture which at least partially drives weapon diameter and cost.

SYSTEM ISSUES

Primary prelaunch system issues which confront the feasibility of the LOAL concept described here are target acquisition, target identification, and weapon launch accuracy.

Target acquisition is primarily a function of altitude, topography, and meteorological conditions. Typical clear line of sight data is shown in Figure 3 which indicates a requirement (for the terrain described in the figure) for pop-up altitudes on the order of 1000-2000 feet. Atmospheric considerations are highly complex and are very important in establishing the utility of a system concept. An example of meteorological consideration is shown in Figure 4 for visibility in central Germany which indicates the impact of atmospheric conditions on a standoff concept requiring clear line of sight to the target. Target identification performance with the current generation of FLIR pods as typified by Pave Tack data for nominal weather condition is presented in Table 1. Subject to meteorological limitations, standoff ranges against high value fixed targets are quite large. Weapon launch accuracy and autopilot performance for the case of the Low Cost Inertial Guidance System developed for the AFATL are consistent with the desire for a small field of view for the LOAL seeker.

Potential weapons applications for the generic seeker under discussion include the GBU-15, Maverick, Hellfire, arc imaging, low-level glide bomb and potentially the Hard Target Weapon.

The critical high risk issues which will be discussed in the following paragraphs are concerned with the reliability of the scene matching process for disparate image sets separated by considerable distance with potentially significant perspective variations. Closely coupled to the scene matching issue is the packageability of the algorithms in a realizable processor (and costs). The material presented next does indicate feasibility but a risk element remains, and is described.

SCENE MATCHING ALGORITHMS AND PACKAGING

Currently, missile handoff processors for LOBL applications are under development in the R&D community (e.g., the Automatic Target Handoff Correlator and Multiple Target Handoff Correlator developed by Goodyear Aerospace Corporation for MICOM and the Missile Boresight Correlator under development by Hughes Aircraft Company for the LANTIRN program).

Such processors typically are based on pixel level correlation. High resolution FLIR imagery is resampled in accordance with the weapon resolution, and the resultant imagery is encoded for arithmetical efficiency (e.g., bilevel, trilevel representation). A window of one image set is moved throughout the region of possible boresight error in search of the peak correlation value. System studies conducted at Ford Aerospace indicate that the major sources of error in pixel level correlation schemes are rotation and scale uncertainties and signal to noise ratio requirements for the two sensors. The latter obviously is strongly impacted by sensor performance characteristics, target contrast, and atmospheric conditions. Analysis of a large data base by Iler of Goodyear Aerospace, and Pitruzzello and McIngvale at MICOM (1979) resulted in the statistical data for the effects of rotation and scale error summarized in Figures 5 and 6. Results of the work of Knecht at NWL (1979) indicated that a signal to noise ratio of approximately 4 is required to achieve a 90 percent probability of successful handoff. Rotational error tolerance determines the roll stability requirement, and scale error tolerance determines the requirement for range knowledge throughout the scene. The signal to noise ratio requirment drives the weapon sensor performance and design parameters and the mission utility related to the FLIR performance at long range.

Although the pixel level correlation schemes are an attractive solution to the handoff for the lock-on-before-launch problem, Ford Aerospace has been investigating scene matching schemes which are relatively insensitive to roll and scale errors and which provide increased tolerance to low signal to noise ratio imagery in the desire to reduce demands on seeker and weapon platform performance. Basic scene matching schemes which typify the approach adopted at Ford Aerospace are emerging from the DARPA Image Understanding Program in the form of stochastic labeling algorithms. In essence, the algorithms provide a probabilistic assessment of the likelihood that an object in one scene is the conjugate object(s) in a reference scene. At the Individual object level the assigned probabilities are based on similarity of features (e.g., shape descriptors and contrast). The likelihood values for conjugate objects are further modified by consideration of the consistency of spatial relationships among objects. A number of

schemes for performing the stochastic labeling process have been employed by various researchers. At Ford Aerospace emphasis has been placed on progressively simplifying the process as allowed by the near real time relationship between the FLIR derived model and the lock-on-after-launch weapon imagery.

The total processing scheme under investigation is illustrated in Figure 7. The key to successful performance in matching scenes is the reliability of the segmentation process in preserving the shape of objects in the two scenes without excessive fragmentation of large regions into small ones. Our emphasis has been to anticipate signal to noise ratio problems through multistage smoothing at the pixel and feature level. The Histogram Optimization Filter, originally developed for processing very noisy CO_2 laser imagery, is developed around a simple concept that in the vicinity of each pixel there exists a "best" window for filtering, or in certain instances the pixel should be considered an edge with no filtering performed. With CO_2 and FLIR imagery the algorithm has demonstrated superior noise suppression and edge preservation properties as compared with mean, median, and holomorphic schemes. After pixel level filtering is accomplished, further smoothing occurs through the use of adaptive clustering to extract localized, essentially homogeneous regions. To account for effects of rotation, distortion induced by perspective variations and scale, we are investigating a new approach to matching the shape of an object to the shape of a reference. The boundaries of the objects are represented by a series of chords. The region comparator algorithm then determines a measure of the degree to which the object obtained in real time must be distorted to resemble the shape of each possible reference object. The other "strong" feature available with a near real time reference model is relative contrast of objects. The stochastic labeling process insofar as we can determine, is unique in the combination of new filtering, clustering, shape analysis and scene matching schemes which can be implemented in real time. Real time processing in the real time environment is necessary to achieve weapon target acquisition and terminal homing. Conceptually, the Pave Tack aided LOAL weapon has the necessary operational ingredients to achieve this. All imagery and evaluations are accomplished in real time, in the real environment, and under operator control.

The attendant key issue of packaging the scene matching algorithms has been addressed for a seeker with a field of view of 100 x 100 pixels imaging at a standard 30 Hz frame rate. The total throughput requirement for the complete set of functions described earlier is of the order of 100 MOPS with the largest consumer of computational resources being the Histogram Optimization Filter. VHSIC technology under development offers solutions to the processor design requirements. We have worked with a current contractor to conceptually define a modular approach to achieve all requirements. This configuration provides a throughput margin of over 100 percent in a volume of 0.25 cubic feet and a weight of 9.3 pounds. Alternatively, the recursive nature of processing in the algorithms might well be accommodated in VLSI technology.

SCENE MATCHING RESULTS

Two examples of scene matching experiments for imagery collected from the same scene at different ranges are presented in Figures 8 and 9. In the

airport scene the aircraft cued at the longer of the two ranges is similar in shape in the two scenes, but careful examination reveals that significant variations in the outlines are present. In the heliport scene objects tend to merge or become separated due to perspective variations. In both instances the conjugate for the cued point in the reference scene was identified as such with a probability much higher than any other association.

Work is needed to identify a data base of scenes continuously viewed throughout a long closure range on a variety of targets. Resolution of imagery at various ranges can be degraded to simulate various levels of seeker performance to form the basis for further scene matching experiments which are crucial for a definitive assessment of the LOAL concept presented here.

CONCLUSIONS

Mission concept definition considerations for a lock-on-after-launch weapon system supported by a FLIR pod have been outlined. The overall mission analysis and seeker design process is summarized in Figure 10. Of particular importance is the definition of minimum essential seeker requirements at close range commensurate with the FLIR precision weapon launch performance and long range imaging characteristics. The high risk area of scene matching algorithms has been emphasized. The resultant system benefits at this stage merit continued investigation of these scene matching schemes to support a Pave Tack assisted lock-on-after-launch weapon system.

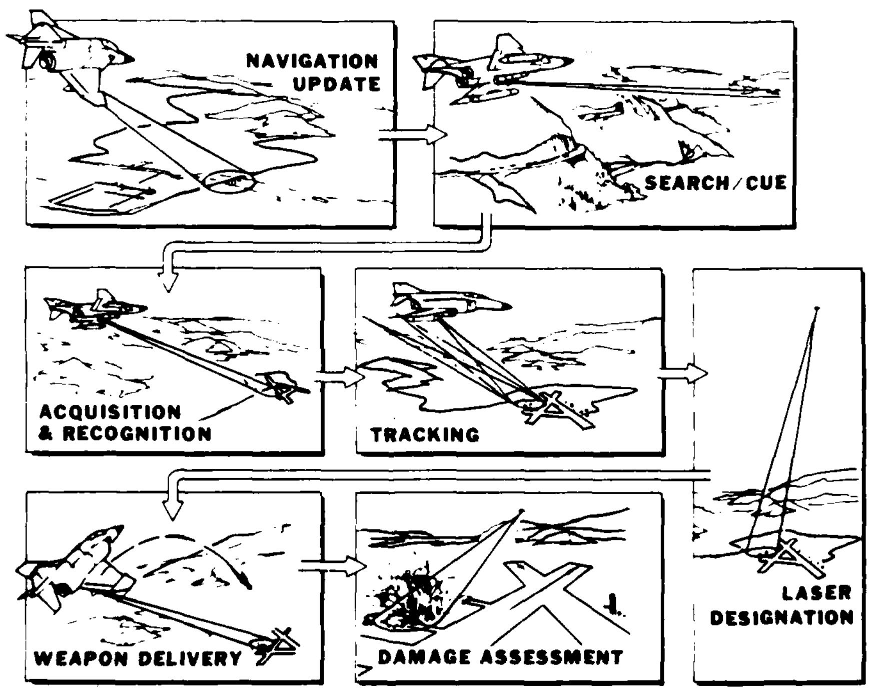


Figure 1. Pave Tack Mission Profiles

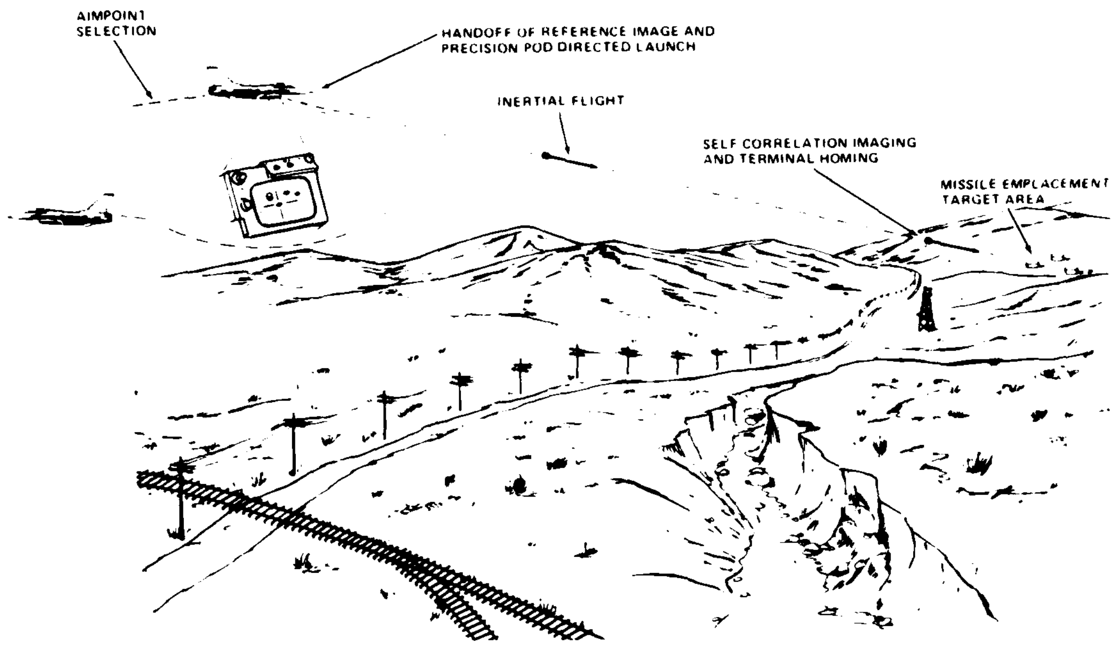


Figure 2. Pave Tack Assisted LOAL Concept

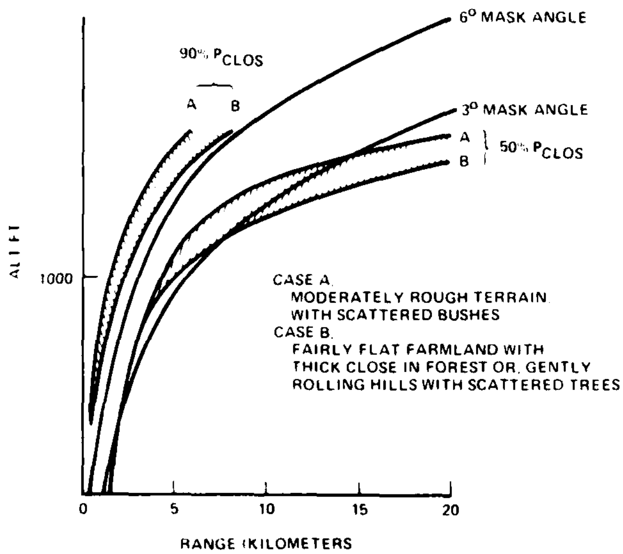


Figure 3. Clear Line of Sight Statistics

Table 1. Typical Pave Tack Target Acquisition Performance

TARGET	PAVE TACK ACQUISITION/ STANDOFF RANGE (km)
POWER GENERATION FACTORIES	30
AIRFIELD, POL's/ REFINERIES, DAMS, RAILYARDS	25
BRIDGES, EW/GCI SITES, C3 FACILITIES	20
FIXED TNF, ARMORED COLUMNS, SMALL BRIDGES	10-12
SMALL TARGETS (ARMOR)	5

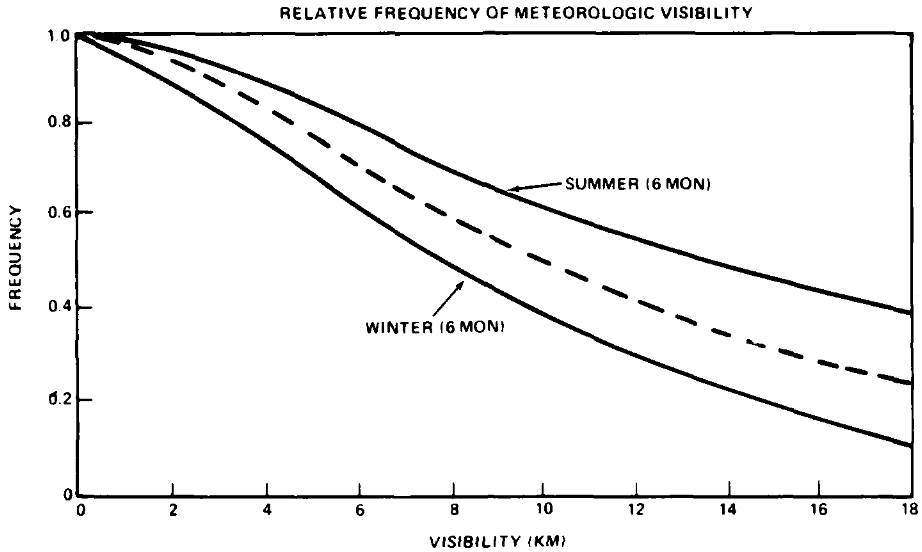


Figure 4. Ceiling/Visibility Occurrence Frequency in Central Germany

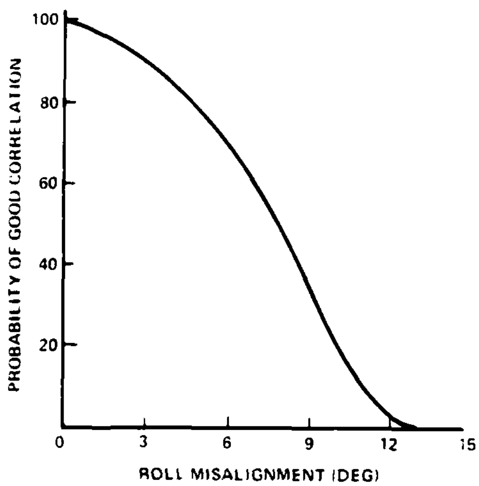


Figure 5. Effect of Roll Stability on Correlation

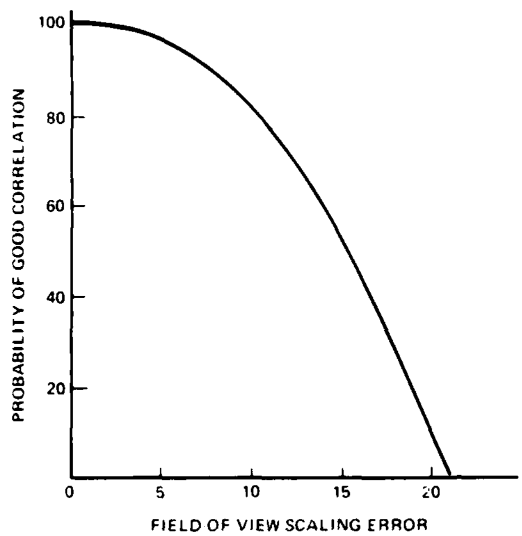


Figure 6. Effect of Range (Scale) Uncertainty on Correlation

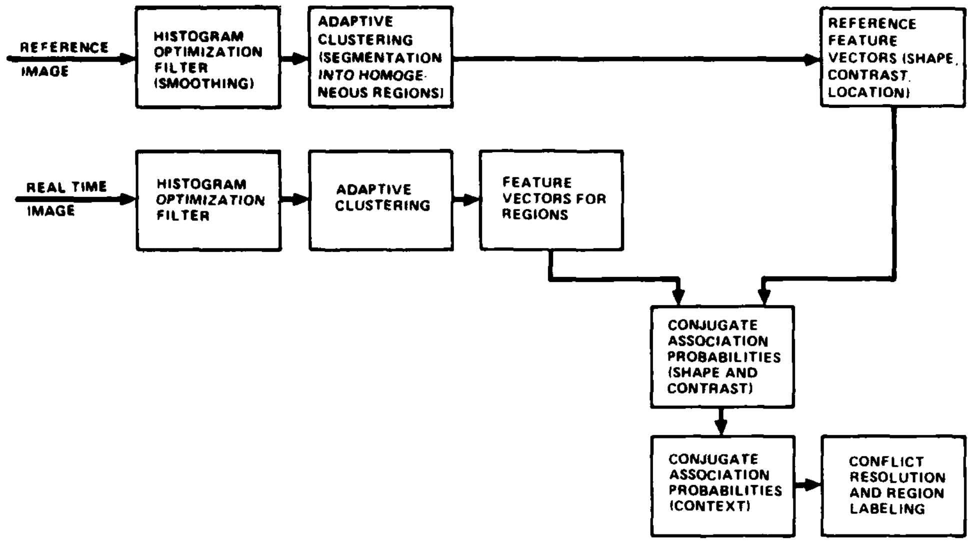
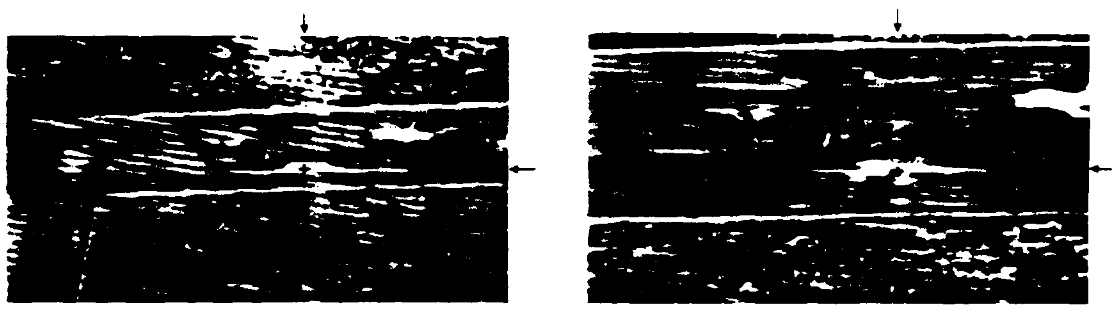


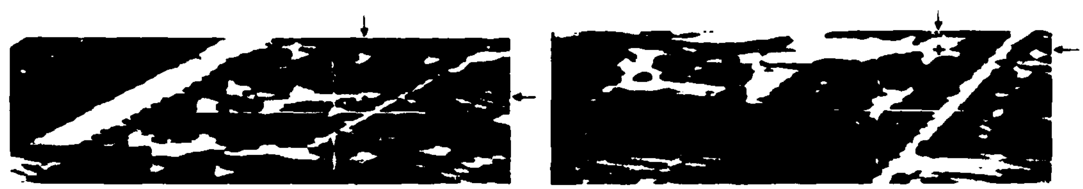
Figure 7. Processing Flow for Scene Matching



CUED TARGET AT COORDINATES INDICATED BY ARROWS

COORDINATES OF CONJUGATE POINT IN CLOSER IMAGE INDICATED BY ARROWS

Figure 8. Airport Scene Matching Experiment



CUED TARGET AT COORDINATES INDICATED BY ARROWS

COORDINATES OF CONJUGATE POINT IN CLOSER IMAGE INDICATED BY ARROWS

Figure 9. Heliport Scene Matching Experiment

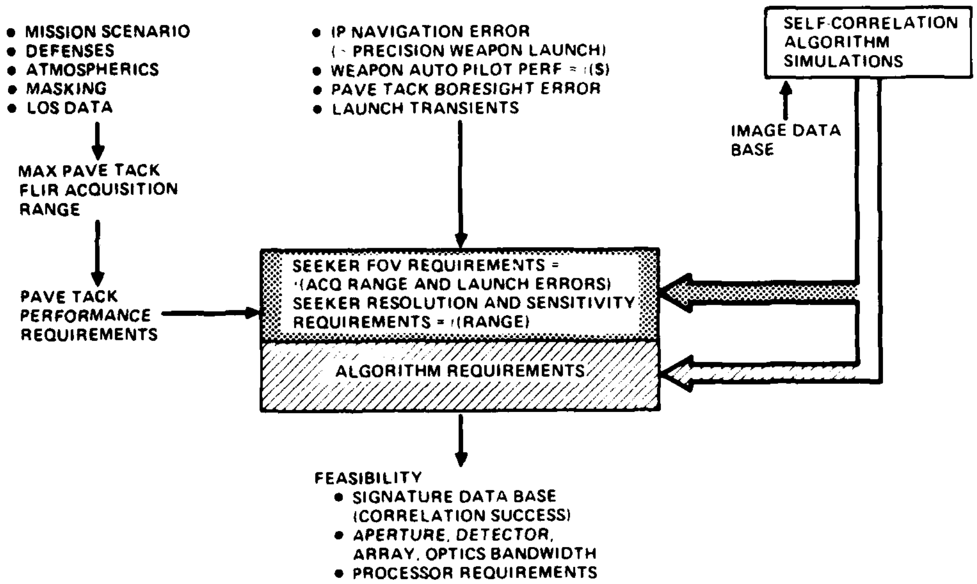


Figure 10. Mission Analysis and Seeker Design Process

INFRARED SEARCH AND TRACK (IRST)
ITS ROLE IN THE NAVY'S OUTER PERIMETER FLEET AIR DEFENSE

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For: ADPA 1982 Annual Meeting on Avionics

1,2,3 December 1982

1. Recent lessons relearned.

The Falklands war at sea and the Israeli's annihilation of the Syrian forces in Lebanon brought into clear focus again some very important points of modern naval warfare. The Falklands war-at-sea demonstrated the vulnerability of naval forces in today's missile age without adequate air superiority and without airborne early warning. It also demonstrated the lethality of even unsophisticated air-to-surface missiles and the requirement to destroy or neutralize the launch platform prior to missile launch range. The Israeli success demonstrated the effective use of intelligence, tactics, training and electronic countermeasures.

2. The threat to the Navy's Carrier Battlegroup.

The same points mentioned above are directly applicable to the present threat to our Navy's Carrier Battlegroup. That threat is of course the cruise missile, launched from submarines, aircraft and surface combatants. Even though the submarine is the worst of the threats, the airborne threat is real and rapidly over-taxing the Battlegroup Commander's available resources to respond. The Soviets have a large number of Backfire bombers available now and are producing more at an alarming rate. The mobility of the Backfire coupled with its long range could make it an immediate threat from any number of land bases possessed by the Soviets or made available by third world countries. Backfires can be in a position to interdict the U.S. Navy and merchant-fleet at any of the six major choke points on the globe; the GI/UK Gap, Gibraltar, the Cape of Good Hope, Singapore, the Sea of Japan, and the Caribbean.

Of course the threat to the Battlegroup is not the Backfire, but the AS-4 and AS-6 air-to-surface missiles carried by the Backfire. With an extremely long missile launch range the Battlegroup Commander has a formidable problem on his hands. Add to that the expected large size of Soviet Backfire raids and you can start to understand the problem. Add dedicated stand-off jammers acting as decoys, disrupting early warning radar and communications, seeding massive corridors of chaff. Finally you add the limited number of airborne fighters available to the Battlegroup Commander and the situation appears worse than the Battle of Britain. The use of intelligence, tactics, training, sophisticated weapon sensors, weapons and electronic warfare are the Battlegroup Commander's answer to the Soviets advantage in pure numbers.

3. The Battlegroup Commander's problem.

Only with fighters, under the positive control of surveillance aircraft, can an attempt to intercept the Backfire be made by the Battlegroup. For the Battlegroup Commander to make extremely efficient use of his limited fighter assets he must be able to:

a. detect and verify a raid at the maximum range possible,
b. estimate the size and composition of the raid,
c. distinguish a decoy feint from the real strike groups, and
d. accomplish these functions in a heavily jammed environment while, at the same time, attempting to hide the Battlegroup as long as possible.

4. Surveillance and fighter problems.

Along with the Battlegroup Commander the crews of the airborne platforms face considerable problems in efficiently using the limited number of air-to-air missiles available to them. Some of the questions facing the crews are:

a. How many targets are we up against? Are the targets the real raid or a decoy attempting to draw us out of position? What's the range, track and speed of the targets?

b. If our radars are jammed how do we get the basic information required to target and fire our missiles and vector deck launched interceptors into the fight?

c. How successful were the air-to-air missiles fired? How many Backfires remain? Have any cruise missiles been launched from the Backfires? How many cruise missiles have penetrated the outer perimeter and are inbound for the Aegis cruisers to handle?

Overriding all these considerations is the most crucial factor - TIME. Every available minute is important to the fighter crews and the Battlegroup Commander from the time of raid detection to time of Backfire weapon release position. Additional time means more deck launched fighters available and more missile firing opportunities. If ranging is denied by radar jamming every minute required for a passive ranging solution means fewer firing opportunities, with Backfires rapidly closing to their weapon release lines.

5. Is Infrared Search and Track a potential solution to the many problems facing the Battlegroup Commander and his defensive crews in the Outer Perimeter?

We must first look at what information is available to the Battlegroup Commander and his crews. Two of the most powerful and sophisticated radars in the world are presently the eyes of the fleet. Designed with long range as a driving requirement, the target azimuth resolution performance is a problem because of the relatively large beam widths involved. Being radars they are susceptible to radar countermeasures regardless of our continued efforts at counter-countermeasures. These radar factors alone make Infrared Search and

Track (IRST) very promising. Other IRST capabilities make it even more attractive.

So what is an IRST system and what should we expect from it? An IRST system is an infrared point detector, not an imager. It is supposed to detect and process point sources of IR energy, automatically reject background clutter and display only target information.

State-of-the-art improvements in the area of focal-plane array detectors, optics, cryogenics, spectral/spacial/temporal discrimination techniques, programmable digital signal processors, and stabilization have brought IRST out of the world of promising ideas and into the realm of reality.

IRST's passive capability in the mid and/or far infrared regions provides detection and tracking in the presence of rf jamming and during EMCON conditions. The ranges will be typical of the high powered, airborne, surveillance radars depending on the conditions of the atmosphere. An IRST sensor can provide extremely high angular resolution and unique target discrimination capabilities.

In addition, IRST capability integrated into missile firing platforms will add flexibility through new multisensor techniques to fire missiles (in jamming) using guidance from the infrared angle-track, to direct radars for longer burn-through ranges, and to do rapid passive ranging.

Although the maturing of many technologies and emergence of new technologies has brought IRST closer to reality, there still remains two major design issues which must be resolved. One issue is which infrared region should be used, mid or far infrared, or both. There are pros an cons for both but pitiful real time data to make a decision. The other more crucial issue is the signal processing. Spectral, spatial, temporal, one color, two color, three color; only a few of the processing techniques being developed and still unproven.

6. Navy's airborne IRST program.

Past airborne IRST systems were developed and flown on fighter aircraft, but were pushing the state-of-the-art to the point that they were not operationally suitable or supportable. The Navy is convinced that IRST systems are ready to be looked at again and if successful will be invaluable to the defense of the fleet. Parallel multi-service programs are underway to ensure that IRST sensors are developed for the fleet as soon as possible after the major design issues are adequately addressed. The Navy is undertaking a comprehensive IR background measurements program which will include IR target and E-O meteorology data to produce raw background data for industry and the services use, and to analyze and report on the many design issues in hardware and software still in question. The Navy hopes to issue a Full Scale Development proposal to industry for a sensor just as soon as the technology is demonstrated. Although the specification is still to be defined, the general requirements for the sensor will demand range and resolution performance sufficient to detect and raid count a Backfire raid at extended ranges, with a negligible false alarm rate.

7. Conclusion.

More than ever before technology is being asked to even the odds against the Soviets overwhelming advantage in numbers. More than ever before the vulnerabilities and shortcomings of radar are being addressed. More than ever before the survivability of ships at sea is being questioned. IRST is one technology which may help us respond to all those concerns and may provide invaluable capabilities for fleet defense. We need the vast talent of America's avionics industry to bring the capability to the fleet NOW.

PAVE MOVER DIRECT ATTACK SYSTEM

by

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Air Armament Division
American Defense Preparedness Association
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PAVE MOVER DIRECT ATTACK SYSTEM

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I. INTRODUCTION

This paper presents the results of a feasibility demonstration of the Pave Mover Direct Attack System. The purpose of the program was to prove the feasibility of using the Pave Mover Radar to locate second echelon moving targets, and to provide a low-flying tactical fighter with critical data about the target relative to the attack aircraft current position.

The feasibility program was accomplished under contract with Eglin AFB during the 1981-1982 time frame(1). New technology was developed, tested, and verified during the feasibility testing. The major points are as follows:

- It was proven that a high-flying stand-off surveillance radar aircraft could communicate to a low-flying tactical fighter using data modulated on the radar signal.
- The radar system delivered accurate position data to the attack fighter so that a dynamic position update could be accomplished to reduce onboard inertial navigation system errors.
- Moving target coordinates were automatically inserted into the navigation/weapons computer from data received from the modulated radar signal.
- An accurate relative grid between the attack aircraft and target, based on radar data, could be used for improved weapon delivery.
- The attack aircraft could be at precise locations at precise times through implementation of newly developed flight path trajectory generation/time-of-arrival algorithms.

The program was very successful and concept validation was accomplished. A totally functional system was demonstrated including blind bombing of remotely controlled moving tanks based completely on data transmitted to the attack aircraft through the radar-modulated signal.

II. CONCEPT DEFINITION

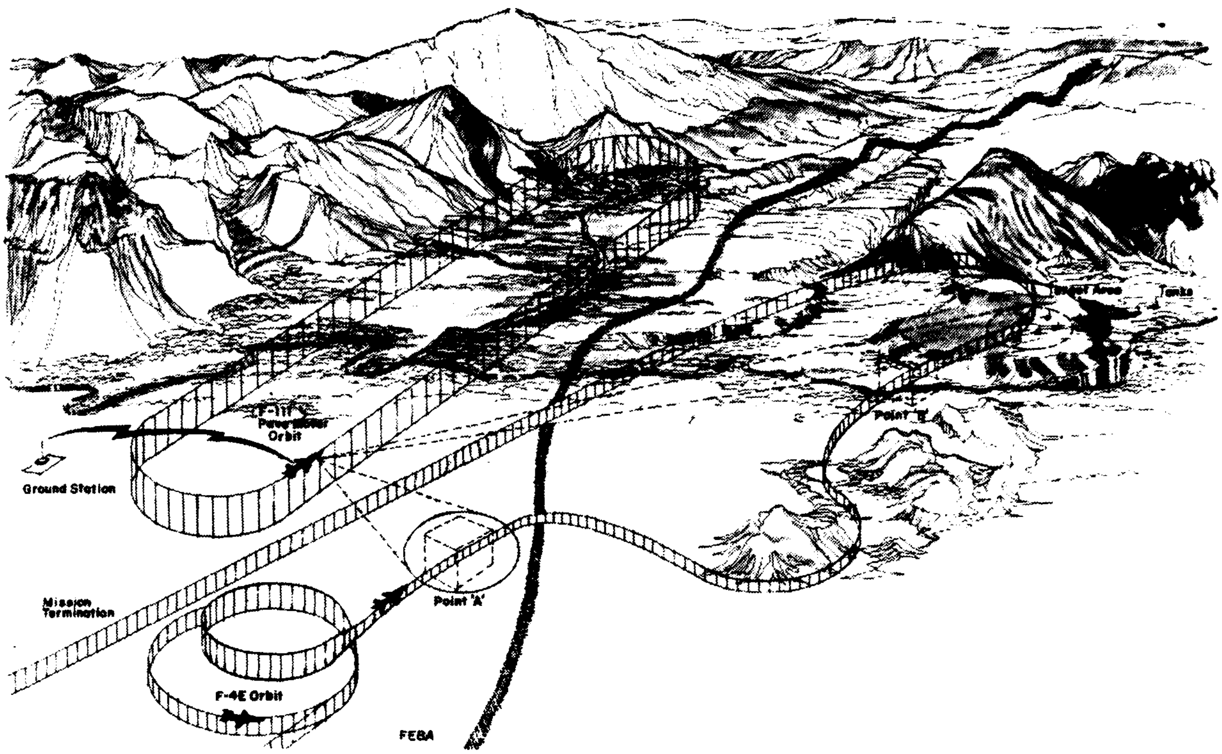
Second echelon high-priority moving targets, especially in the European theater, will be critical tactical targets during war. Because a force multiplier is needed to neutralize such mobile forces, the USAF, under management of the Electronics Systems Command, has implemented a new system called the Pave Mover Direct Attack System.

The Pave Mover Direct Attack System is comprised of a stand-off surveillance radar aircraft, an associated data processing station (located in either in the radar aircraft or in a ground shelter), and an attack aircraft.

The radar system features a state-of-the-art synthetic aperture side-looking radar. The radar utilizes a multimode capability of mapping, area of interest zoom, and moving target indication (MTI).

The total system concept is depicted in Figure 1. Shown here is the Pave Mover Radar system aircraft in orbit on the "safer" side of the forward edge of the battle area (FEBA), communicating data to and from the data processing station located on the ground.

The Pave Mover Radar system comes on station in a particular orbit, to allow coverage of an assigned area along the FEBA. After painting the first segment of the area with its radar beam and submitting data to the ground processing station, an image interpreter interrogates one of several CRT displays. Upon detection, classification, and



PAVE MOVER DIRECT ATTACK FLIGHT SCENARIO
FIGURE 1

prioritization of a target, the interpreter transmits the target data to the Tactical Command Center. In the Command Center an allocation of resources is made and attack requirements and/or target assignments are sent back to the ground processing station. The station formats the attack data, interrogates the Pave Mover Radar aircraft with beam-pointing information relative to the target and attack aircraft, and then directs target assignment to the appropriate attack aircraft.

While the Pave Mover Radar aircraft has been collecting initial data, one or more attack aircraft have come into the mission assignment area. Now that a target has been detected, identified, and an attack order given, the radar aircraft re-acquires the target and updates the target data; then attack aircraft acquisition is accomplished by the radar aircraft. The target assignment data along with attack aircraft present position data and communication or attack times are submitted to the attack aircraft. This is accomplished by data modulated on the radar signal.

A transponder within the attack aircraft receives the signal through specially installed antennae, extracts the data and submits the data to the navigation/

weapon delivery computer. The navigation/weapon delivery computer then accomplishes position update of the attack aircraft navigation system and initializes a flight trajectory computation within the computer which provides steering and speed control commands so the aircraft will arrive at the next communication point and/or the target at a commanded position at a precise time.

The attack aircraft then proceeds to the target area along a low-altitude computed trajectory under either manual or automatic flight control at the pilot's discretion. Trajectory routing is computed by using predetermined avoidance areas and/or communication waypoints transmitted by the radar aircraft. The pilot is free to disregard the steering/speed commands and a continuously computed new trajectory will be determined from the aircraft current position. Generally, several communication waypoints enroute to the target will be used so that periodic update of the target parameters and attack aircraft position can be accomplished, thus assuring more accuracy in the target area in case communications between the aircraft are lost.

On the way to the target area, the aircraft crew can decide to deliver ordnance either by flying along the major axis of the moving armored vehicles or by using a curved flight path weapon delivery mode (thereby eliminating direct flyover) for improved survivability in high threat areas.

The wide area armor munitions to be dispensed are carried in the newly developed tactical munitions dispenser which is a 1000-pound class high-drag cargo carrier. The cargo can be any of the newly developed submunitions such as ACM, Gator, or Skeet. Once target attack is accomplished, flight path route generation by the computer is accomplished to get the aircraft back through the FEBA using the safest known route.

The attack aircraft has the capability of autonomous weapon delivery anytime after target assignment if Pave Mover Radar communications are lost. Accuracy obviously degrades as a function of time from the last update.

The system is completely unrestrictive and allows the pilot freedom to fly his aircraft as the situation requires. The automatic trajectory and time-of-arrival system will compensate for any maneuvering and will continue providing the latest best route to target based on the aircraft current position.

III. FEASIBILITY TESTING

Testing was performed at White Sands Missile Range with the aircraft housed at Holloman AFB, February through August, 1982. Testing was accomplished under the Direct Attack portion of the Assault Breaker program.

The feasibility demonstration system was made up of the following hardware:

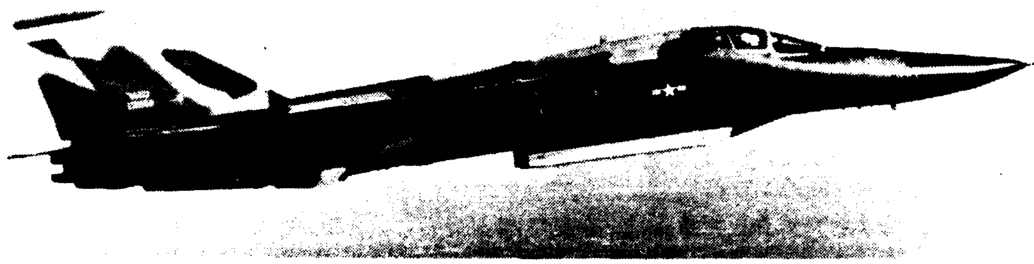
Pave Mover Radar Aircraft

- Hughes system in F-111 bomb bay (Figure 2)
- Grumman/Nordan system in F-111 bomb bay (Figure 3)

Pave Mover Data Processing Station (Figure 4)

- Hughes ground station
- Grumman/Norden ground station

F-111 WITH HUGHES RADAR POD
FIGURE 2



F-111 WITH GRUMMAN RADAR POD
FIGURE 3

GROUND PROCESSING EQUIPMENT AND TEST FACILITIES
FIGURE 4

Penetrating Attack Aircraft

- Lear Siegler, Inc. Direct Attack System in F-4E

The Pave Mover radar features the following:

- Synthetic aperture sidelooking radar
- Multimode
  - Mapping
  - Area of interest zoom
  - MTI
- Digital communication data multiplexed on radar signal
- Transponder tracking of the attack aircraft
- The radar antenna subsystem mounted in F-111
- The radar signal processing and control subsystem housed in a ground shelter

The Direct Attack F-4E system features the following new potential operational capabilities tested during the feasibility demonstration program.

- Automatic aircraft flight path generation
- Automatic time-of-arrival control
- Automatic antennae switching to assure good communication with the radar aircraft
- Advanced weapon delivery consisting of:
  a. Standard blind weapon delivery with the newly developed tactical munitions dispenser (TMD), and the Gator or ACM submunitions
  b. Curved flight path weapon delivery with conventional or TMD and Gator or ACM submunitions
- Automatic dynamic aircraft position update from standoff radar data
- Automatic dynamic moving target assignment
- Autonomous weapon delivery on the moving targets, after target assignment, if radar communications are lost.

The two radar contractors used common data words so Lear Siegler, Inc., the F-4E integrating contractor, had only one data interface to work with. However, electrically the systems differed and separate transponders and antennae had to be used. The F-4E was configured with both sets of equipment so testing could be accomplished with either radar system.

The transponders interfaced with the F-4E aircraft AN/ARN-101 Central Computer through a new unit called the antenna switching unit. This unit provided antenna switching from upper to lower antenna depending on a continuously computed line-of-sight vector from the F-4E attack aircraft to the Pave Mover Radar F-111.

Current positions of the F-4E and F-111 as well as the F-4E attitude were used to determine the line-of-sight vector. This provided an all-attitude communication capability whenever a line of sight between the two aircraft existed.

In addition, the antenna switching unit accumulated the data received through the transponder, reformatted it for compatibility with the AN/ARN-101 computer, performed a data integrity check and, if everything was right, transmitted the data into the central computer.

New algorithms developed to perform these missions were added in the spare memory portion of the AN/ARN-101 central computer while retaining all the existing features of the on-board equipment.

A slight digression might be in order at this time in order to explain in a little more detail some of the new technology developed and tested.

First, let's look at trajectory generation and time-of-arrival control. This technology has been in development at Lear Siegler, Inc. for approximately eight years under the direction of the Air Force Wright Aeronautical Laboratories, Wright Patterson Air Force Base. These activities have been reported at several symposia in the past[2,3,4].

While the previous work was involved primarily with algorithm development and attendant simulation, this current program was the first time that trajectory generation and time-of-arrival control was implemented in a tactical fighter and flight tested to verify performance capabilities.

As tactical aircraft continue to get more complicated, the pilot tasks get more extensive and time consuming. This could be fatal in a high threat environment when the pilot can easily get overworked. Trajectory generation and time-of-arrival control were developed to help get the pilot into a aircraft manager role and reduce his workload.

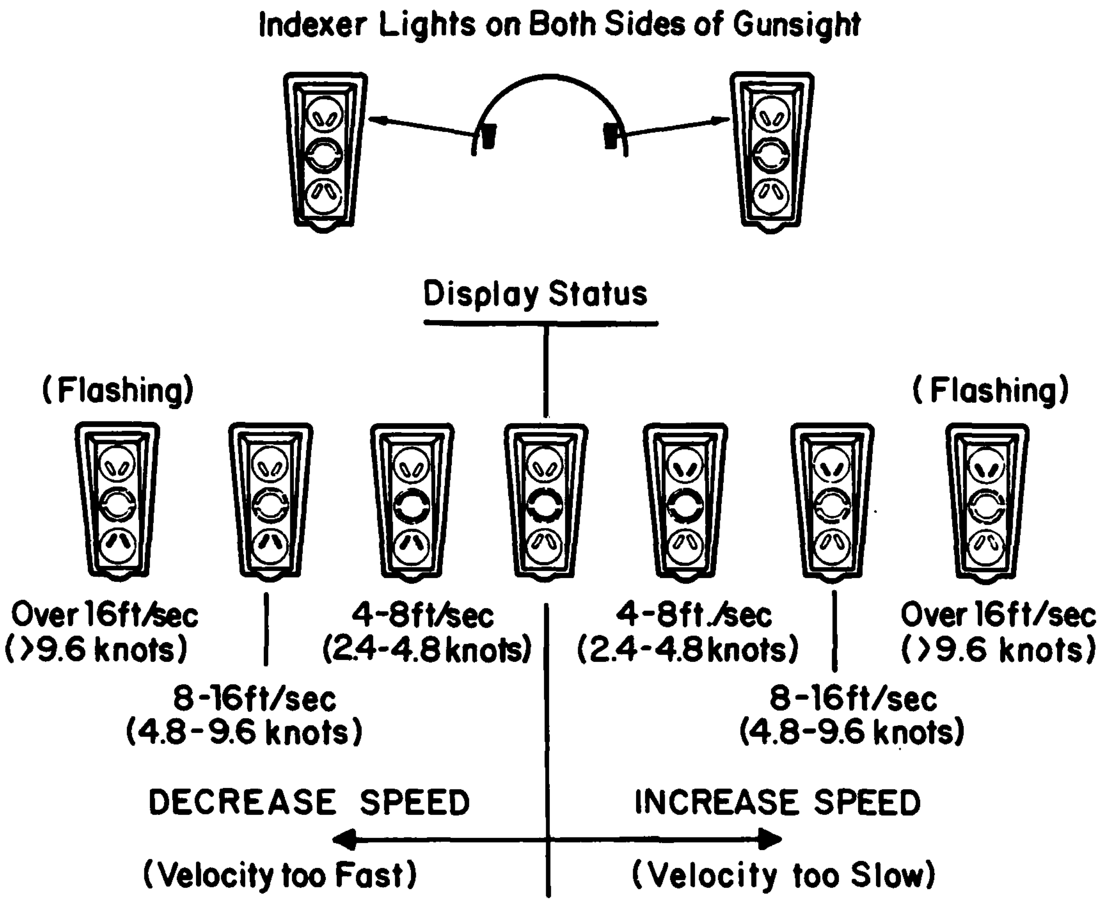
The capability, as implemented, incorporates a dynamic algorithm which continuously computes a trajectory from the aircraft current position to the desired terminator which may be a communication waypoint or the target.

The algorithm uses current aircraft position, heading, and velocity with desired heading, desired velocity, and desired time of arrival at the terminator to determine a flight trajectory in the horizontal plane. The system develops speed commands to control the time of arrival based on the computed trajectory. When speed commands reach selected limits, flight path changes are used to satisfy the desired time of arrival. The pilot may deviate from the recommended flight path since the continuously computed flight path is being generated from the current position to the terminator. If the pilot goes off the desired course so much that a combination of flight path change and aircraft speed changes within selected limits still prevent the aircraft from getting to the terminator on time, a warning is given to the pilot. The pilot can decide to follow the steering commands and thus arrive on time or continue going off course. All functions will operate normally if he continues off computed course except time of arrival will not be met.

Steering commands are presented on the gunsight, ADI, and HSI. Speed commands in the F4E were implemented by using the indexer lights located beside the gunsight to provide head-up capabiliy. The indexer lights were implemented with a seven-state speed granularity using 450 knots as the on-speed nominal center (Figure 5).

Even though this is a rather crude display, the flight crews adapted very quickly and had no trouble zeroing the speed commands and generally liked the head-up capability -- especially during low-altitude target approaches.

Another significant feature developed was the dynamic position update from Pave Mover Radar data.



F-4E SPEED COMMANDS
FIGURE 5

The Pave Mover Radar provided unfiltered attack aircraft position data. This data was implemented through a simple averaging filter and used as a position update source for the attack aircraft inertial navigation system. The radar system also provided filtered target coordinates. These two sets of parameters were used to establish an accurate relative grid between the attack aircraft and the target from which weapon delivery was accomplished.

The relative grid provides improved weapon delivery since radar errors common to both the target and attack aircraft are washed out.

The fully automatic position update required no crew action. The aircraft central computer would accept the Pave Mover data if the difference between that data and the INS data did not differ by more than two nautical miles.

Acceptance of Pave Mover data is indicated by lighting the data link light on the AN/ARN-101 keyer control panel. The pilot can estimate his system relative accuracy by how long it's been since an update has occurred. Rejection of data merely kept the system in the autonomous mode while continuing to look for another update.

IV. TEST RESULTS

Testing this weapon system concept demonstrated it to be feasible. The specific test results are classified and are not included in this paper.

While tactical munitions dispenser (TMD) weapons were not dropped as planned due to lack of availability, the system has implemented the new TMD ballistics for both the Gator and ACM and it is ready to use the weapons when they become available.

The MK 106 practice bomb was used in place of the TMD and was dropped at the computed center of the area covered for the TMD. Data analyses then took the TMD wide area coverage capability into account to show multiple tank kill capability based on the actual impact point of the MK 106 bomb and the tank locations at time of impact.

The results of bombing were very satisfactory and the blind bombing relative grid accuracy, trajectory generation, and time-of-arrival control all met the program goals. The system demonstrated bombing without the need for a "pop-up" to visually locate the target.

The tanks under test were modified to incorporate remote control. This allowed unmanned moving tank column targets to be utilized in the tests. All bomb drops were performed on these moving targets.

V. SYSTEM ADVANTAGES

The concepts demonstrated feasible will provide the Air Force with a force multiplication capability by being able to blind bomb moving armor in the enemy second echelon with accuracy. A single-pass, low-altitude, multiple-kill capability was demonstrated.

Also, the flight trajectory generation capability to steer the aircraft around known threats, coupled with the radar common grid which eliminates the need for a "pop-up maneuver" in order to locate the target, will provide improved survivability.

Major axis definition from the radar improves the single-pass kill probability. The weapons will be distributed at low altitude along the major axis of the enemy vehicles on the first pass with minimum aircraft exposure to enemy fire.

Precise time-of-arrival control of the attack aircraft at any designated point or time provides more efficient utilization of assets.

The system is ready for full-scale development. The trajectory generation, time-of-arrival control, and accurate relative grid technologies are not unique to the Pave Mover Radar, and, in fact, can operate with any external targeting sensor.

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